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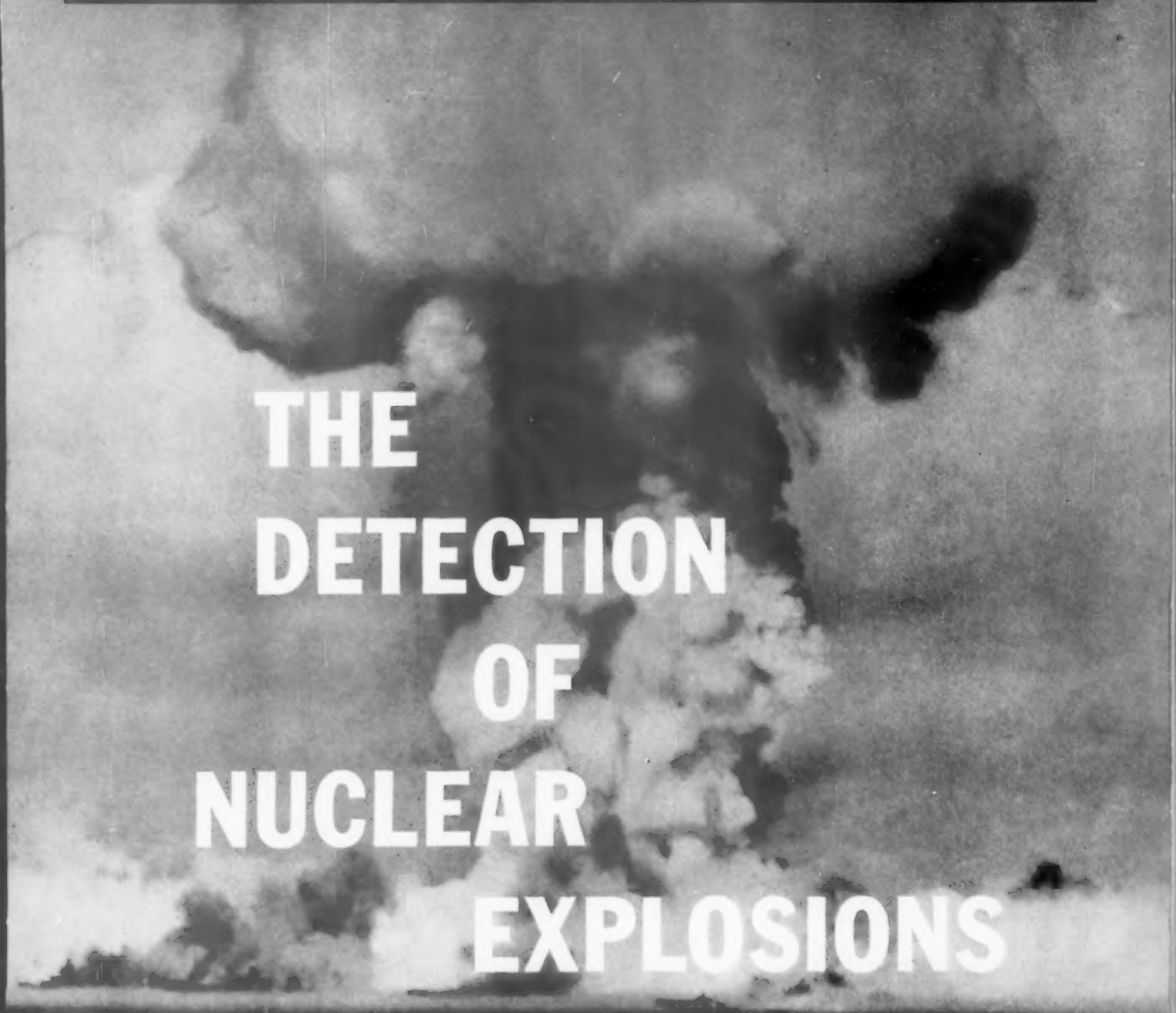


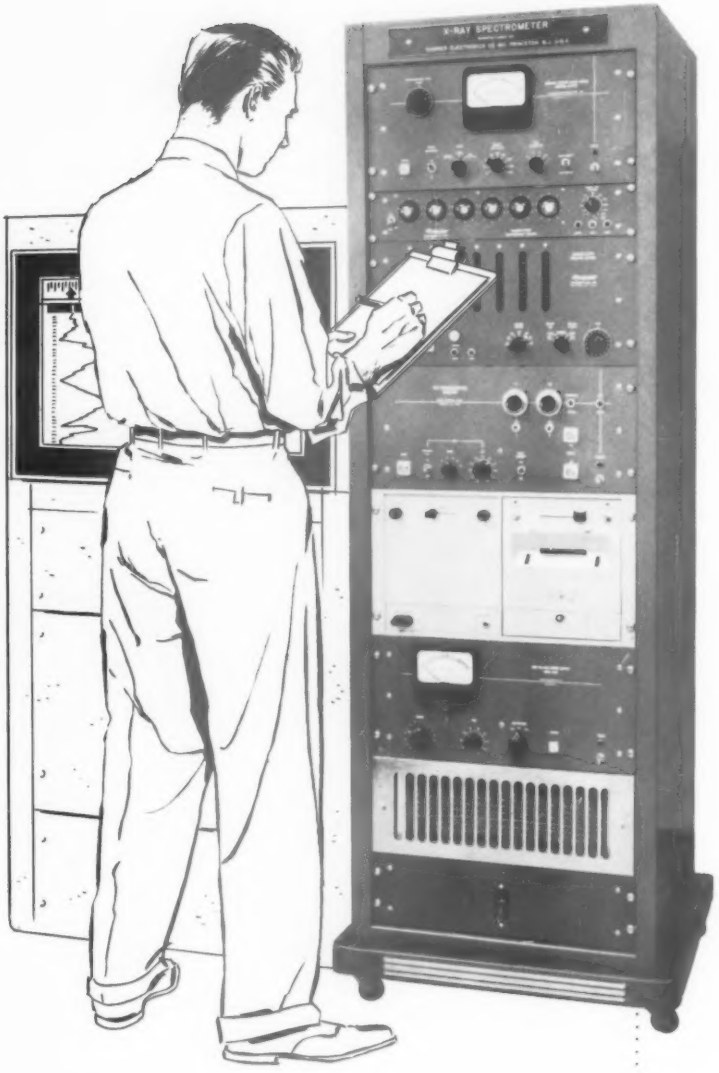
THE DETECTION OF NUCLEAR EXPLOSIONS

The available methods and their sensitivities... p. 64

Instrumentation for Automatic Spectrum Recording

BY

Hamner



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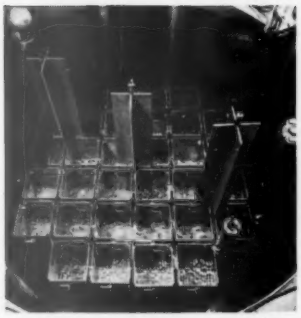

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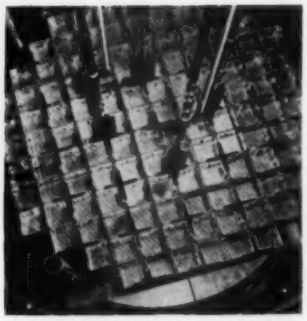

Critical experiment core for the thorium converter reactor designed and being built by B&W for the Consolidated Edison Company of New York (Indian Point).

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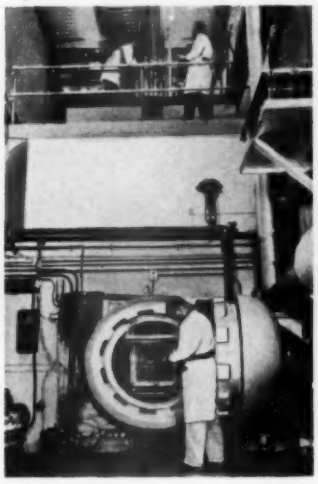

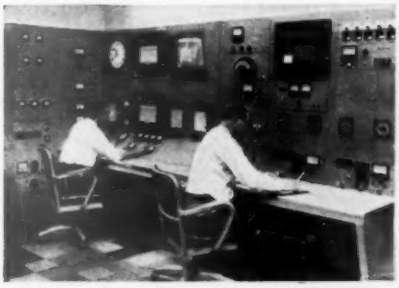

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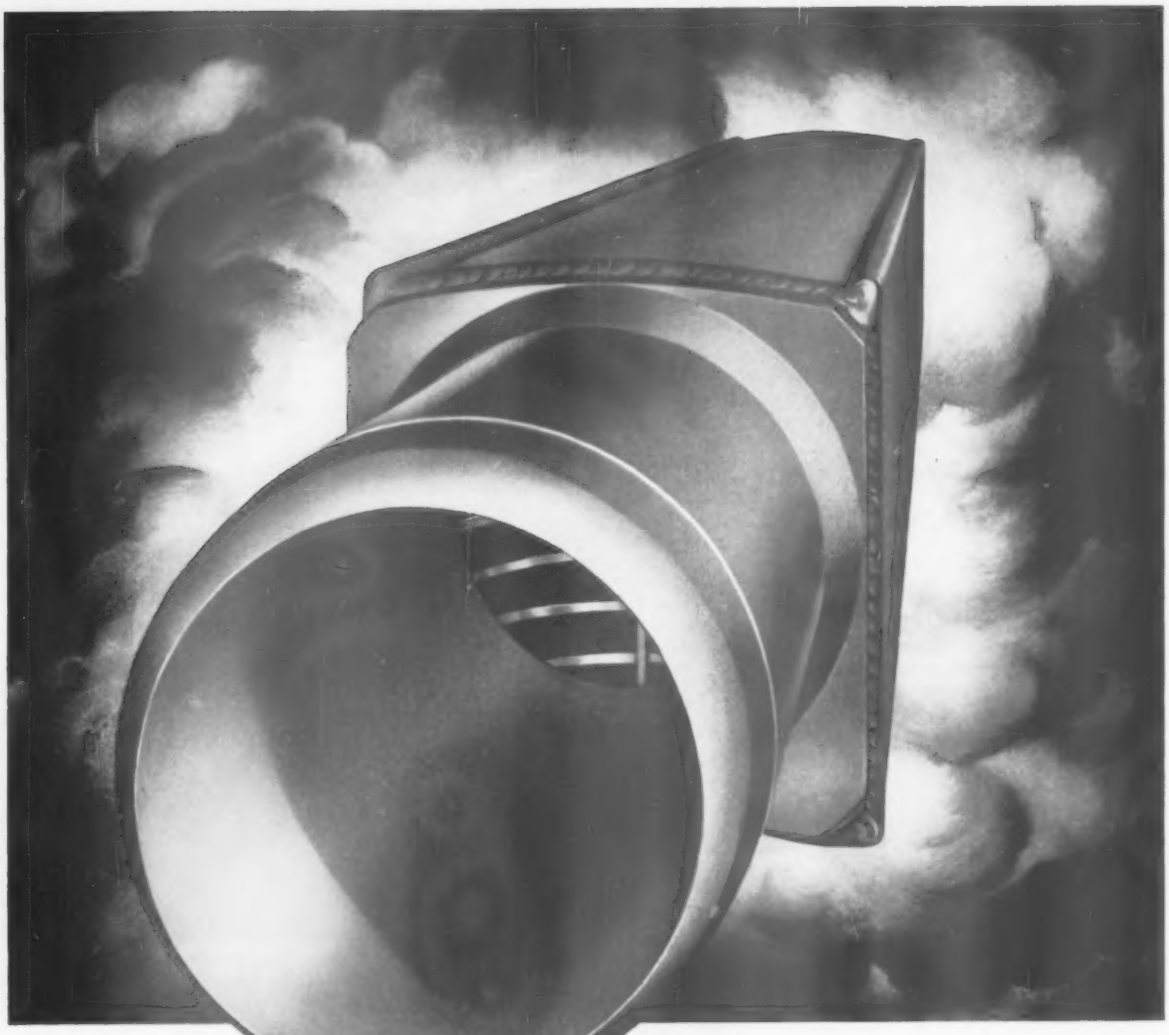

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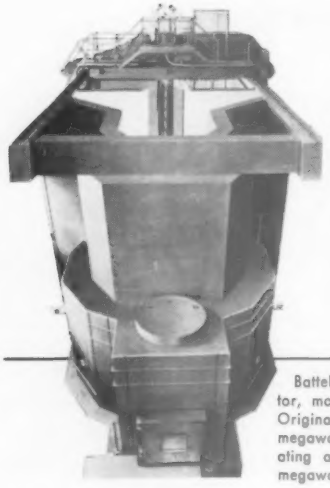

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Feature Articles

Advanced Reactor Studies 59

Engineering Comparisons — S. BARON 60

D_2O-Natural Uranium Reactor — G. F. HOVEKE and J. DeFELICE 63

The Detection of Nuclear Explosions — CARSON MARK 64

Effect of Alpha-Beta Thermal Cycling on Uranium and Its Alloys — B. R. HAYWARD 74

Data Sheet No. 33—Vibration of Rods in Parallel Flow — DAVID BURGREEN 78

Review of French Progress in Nuclear Instrumentation — M. SURDIN 80

Instrumentation and Measurements

Neutron Gage Measures Liquid Level in Intense γ-Ray Fields — T. W. MIX, D. T. MORGAN, F. N. HAUBENREICH, J. R. BOWEN, W. M. QUAM and D. C. MORSE 84

Transistorized Area Monitor Uses G-M-Ion-Chamber Probe — H. A. BROWN and J. V. ROGERS 88

Nuclear Engineering

APDA Introduces Statistical Hot-Spot Factors 92

Limited Leakage vs Canned-Rotor Pumps — L. G. HAUSER 97

Applied Radiation

Radiation Protection Standards Revised 100

Ceric Dosimetry: Accurate Measurements at 10^5 Rads — J. T. HARLAN and EDWIN J. HART 102

Ceric Dosimetry: Routine Use at 10^5–10^7 Rads — SAMUEL I. TAIMUTY, L. H. FOWLE and D. L. PETERSON 103

Departments

NUCLEAR REACTIONS	6	INDUSTRY NOTES	124
ROUNDUP	17	NUCLEAR CAMPUS	125
BOOKS	112	NEWSMAKERS	126
PRODUCTS AND MATERIALS	116	NUCLEAR CALENDAR	128

More about NUCLEONICS on next page ▶

About NUCLEONICS

Deadly Serious Matter

The most recent chapters in the sad history of attempts at reducing the threat of nuclear warfare are the year-old negotiations of U. S., U. K. and USSR in Geneva. The negotiators (James J. Wadsworth for the U. S., Sir Michael Wright for the U. K., and Semyon K. Tsarapkin for the USSR) are striving to reach agreement on a ban on tests of nuclear weapons. Results thus far are limited indeed—such questions as who would sit on the control commission, what would its powers be, which of its actions could be vetoed by a major power, etc. are proving to be beyond solution in the present state of international affairs.

A ray of hope in this gloomy situation is provided by the very real success of a conference of technical experts that was convened in Geneva to prepare the way for the negotiations by considering the technical bases for detecting violations of a test ban. Meeting from July 1 to August 21 of last year, representatives of East and West were able to reach agreement on a network of control posts and detecting equipment that would have the capability of detecting nuclear tests above a certain size range. Carson Mark, head of the theoretical division at Los Alamos, was a scientific advisor to the U. S. delegation. In the article that starts on p. 64 of this issue he discusses the detection problem and its existing solutions. His conclusions lend hope that a test ban would prove enforceable from a technical point of view.

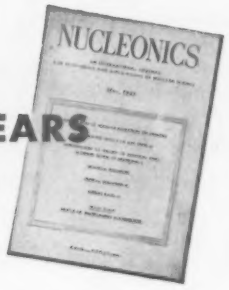
If a ban on nuclear tests were to be agreed on and an international network of control posts established, it would open a new sort of career for nuclear and other specialists. The Geneva experts envisioned a network of 160–170 land-based control posts and about 10 ships. Each control post would require "about 30 persons with various qualifications and fields of specialization." Air-sampling by aircraft carrying out regular flights would also be included in the proposed detection net. Clearly there would be job opportunities in this endeavor of transcendent importance.

BWR, PWR, OMR and D_2O

Last Fall the AEC commissioned design studies of power stations using advanced versions of pressurized-water, boiling-water and organic-moderated reactors. These were for hypothetical construction in 1960 and were designed to provide a basis for comparison of the economic potential of these three types. We have distilled that which is interesting and significant from the studies into a five page report that begins on page 59. For good measure there is included a discussion of a natural-uranium heavy-water design with which NDA and Sargent and Lundy were entrusted.

—The Editors

10 YEARS AGO



Gamma-ray camera. The distribution of gamma-ray-emitting substances can be determined with the aid of a pinhole camera. Using the same principle as in a pinhole camera for visible light, but with heavy lead shielding surrounding the pinhole, satisfactory images of the distribution of the radioactivity in radium-bearing needles have been made. Problems of collimator design have also been investigated—all are discussed in this early article on a technique that keeps being rediscovered.—D. E. Copeland and E. W. Benjamin, NUCLEONICS, August 1949, p. 45.

Reactor instrumentation. If you're new to the nuclear field and would like an easygoing introduction to the instrumentation problems associated with nuclear reactors a survey article in the August, 1949 issue of NUCLEONICS may prove helpful. The fundamental requirements for reactor instruments and the ranges over which they must operate are tabulated and the problems of operation and maintenance are discussed. Particular reference is made to instrumentation of the sodium-cooled reactor then under consideration at Knolls Atomic Power Laboratory.—D. Cochran and C. A. Hansen, NUCLEONICS, August, 1949, p. 4.

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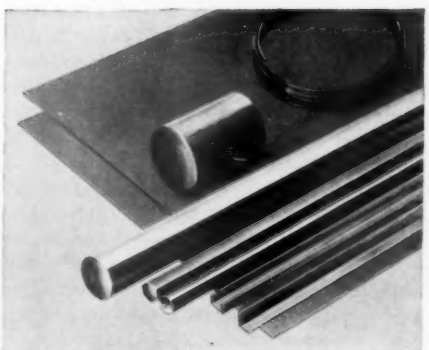

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NUCLEAR REACTIONS

A Vote for Binary Scalers

DEAR SIR:

The article by H. F. Stoddart on "Scalers" (NU, June '59, p. 78) is a good review of current developments in scaling circuitry. However, I would like to point out that binary scalers are not quite as inconvenient to use as the article suggests.

If a binary scaler is equipped with a scale selector switch, then for practically any counting experiment it will be possible to choose a scale factor for which it is not necessary to read the residual count in the scaler at all. It is well known that there is always a probable error in any random counting measurement. If the register reading is numerically larger than the scale factor, the standard deviation of a counting measurement is greater than the residual count in the scaler.

The scale selector should step by factors of 2, since this changes the ratio of the register reading to the scale factor by a factor of 4, which is reasonably convenient. This is easily provided with binary scalers, although unfortunately, too few instrument manufacturers make it available.

Most binary scalers trip the register once on resetting if there is a residual in the last binary stage, so that if the register is read after resetting, it will be correct within ½ register unit, and the probable error resulting from ignoring the scaler residual will be symmetrically distributed about the readings and negligible compared to the probable counting error, provided the "rule of thumb" given above is followed. No systematic error results from rounding off readings in this way, and the standard deviation is increased by 6% or less.

A useful technique is to modify "stop" and "reset" controls to automatically reset the scaler circuit to zero when the counting is stopped, so that the register is immediately ready to read.

For a fixed register speed, the minimum counting time under this procedure is proportional to the square root of the number of pulses counted. For experiments in which very small statistical errors are required, and the counting rate is sufficiently high, it may be useful to use a very-high-speed binary scaler, followed by a moderate-speed decimal scaler for readout.

This procedure does, of course, require that the scale factor be recorded for each reading and that the experimenter know what magnitude of reading to expect. However, after the preliminary phases of an experiment, counting rates or numbers are sufficiently predictable for this purpose.

The extra effort to make the choice of correct scale factor has the merit of keeping the experimenter conscious of the magnitude of the statistical errors in his data while he is doing the experiment and helps to prevent both discarding significant data and recording useless data.

—SYLVAN RUBIN, Senior Physicist
Nuclear Engineering Section
Stanford Research Institute
Menlo Park, California

Dose and the Law

EDITORS' NOTE: *The writer of the following letter has recently published "Evidentiary Problems in Proving Radiation Injury" (Industrial Hygiene Journal* **20,** *111, 1959). He is with the AEC in Washington and is a member of the Tennessee Bar.*

DEAR SIR:

Your recent article " . . . Pocket Dosimeters? Film Badges . . . Or Both?" [NU, May '59, p. 116] was most stimulating and should be of particular interest to the legal profession as well as technical personnel. A review of the X-ray and radium cases which have reached our courts indicates that one of the most difficult evidentiary problems is that of proving actionable radiation injury or defending against such claims. Personnel monitoring records have played a relatively unimportant role in these past actions, most of which have been based on alleged malpractice with radiation emitters. There is some legal precedent for admission of evidence regarding film badges, notwithstanding statements to the contrary. This has not been an important issue in the past, however, inasmuch as personnel instrumentation was not routinely and generally used in radiation work prior to the advent of the atomic-energy program.

Dosimeter readings may be of little value to a defendant from a legal viewpoint unless worn in conjunction with film badges. This is particularly true if the maximum reading of the dosimeter is 200 mr and it is discharged com-

pletely. If the dosimeter is worn with a film badge the latter can be developed immediately to establish the actual dose.

There are *two* problems in utilizing personnel monitoring records to legal advantage. The first is to get the records before the court and admitted into evidence. The second is to prove that the data in the records are accurate and meaningful. More is involved than proving the authenticity of the employee's initials beside a notebook entry. If dosimeter or film badge records are properly maintained and a suitable foundation is laid for their introduction, either may be placed into evidence under a particular set of facts in most jurisdictions. Certain objections may be raised, however, with regard to dosimeter records standing alone that would not prove to be a serious problem with regard to film badge records where the films in question and an expert are available.

Even though admitted into evidence, dosimeter records may be subject to impeachment, and expert testimony may be required to establish their probative value. Numerous questions may be raised, for example, regarding the calibration, or lack of calibration, of dosimeters or pocket chambers, the possibility of improper charging, the type and energy of radiation to which the employee (and dosimeter) was exposed. Was a warm-up period allowed for the charging instrument? Can it be established that the employee actually wore the dosimeter in a proper position? What proof is there that he wore the dosimeter at all times when potentially exposed? Many other questions in this vein may be posed to question the evidentiary value of the dosimeter records.

Film badges *can be* a defendant's most persuasive evidence that a plaintiff did not receive an injurious dose of radiation. It is imperative, however, that film badges be issued, worn, developed and retained under known, controlled conditions.

Ideally, film badges and dosimeters should be worn together. If a choice must be made, however, I believe that a strong case can be made for choosing the film badge on purely legal considerations.

The above opinions, of course, are those of the writer and do not necessarily reflect the views of any federal agency or other official body.

—Gerald L. Hutton
U. S. Atomic Energy Commission
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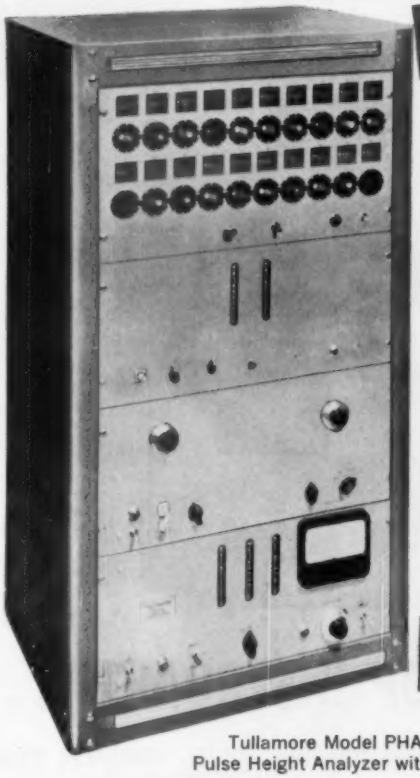

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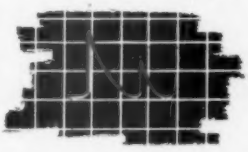

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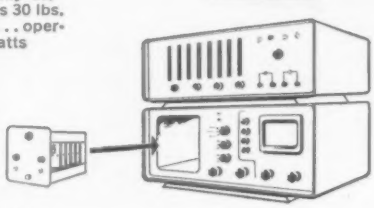

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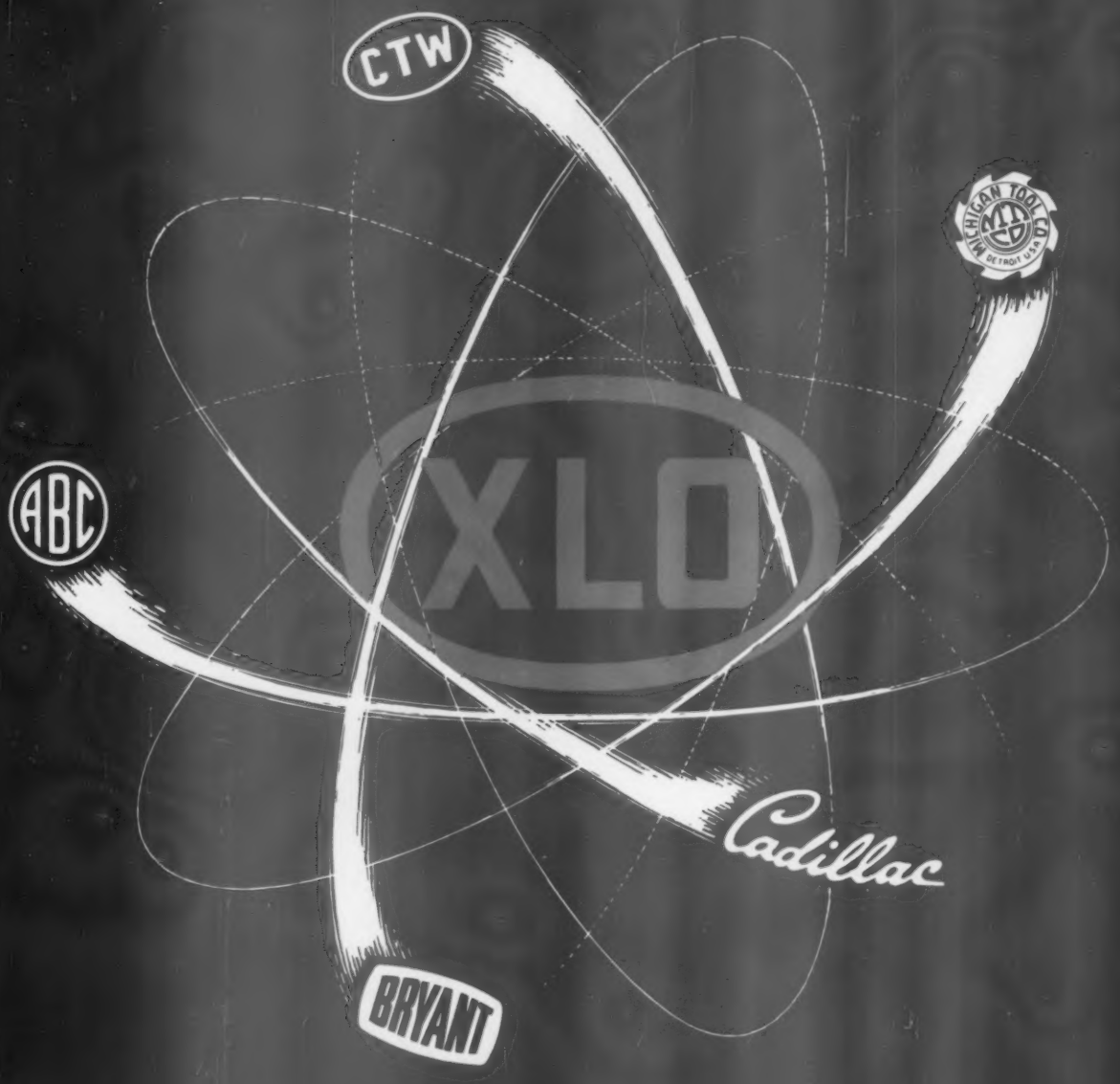

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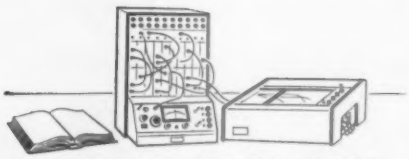

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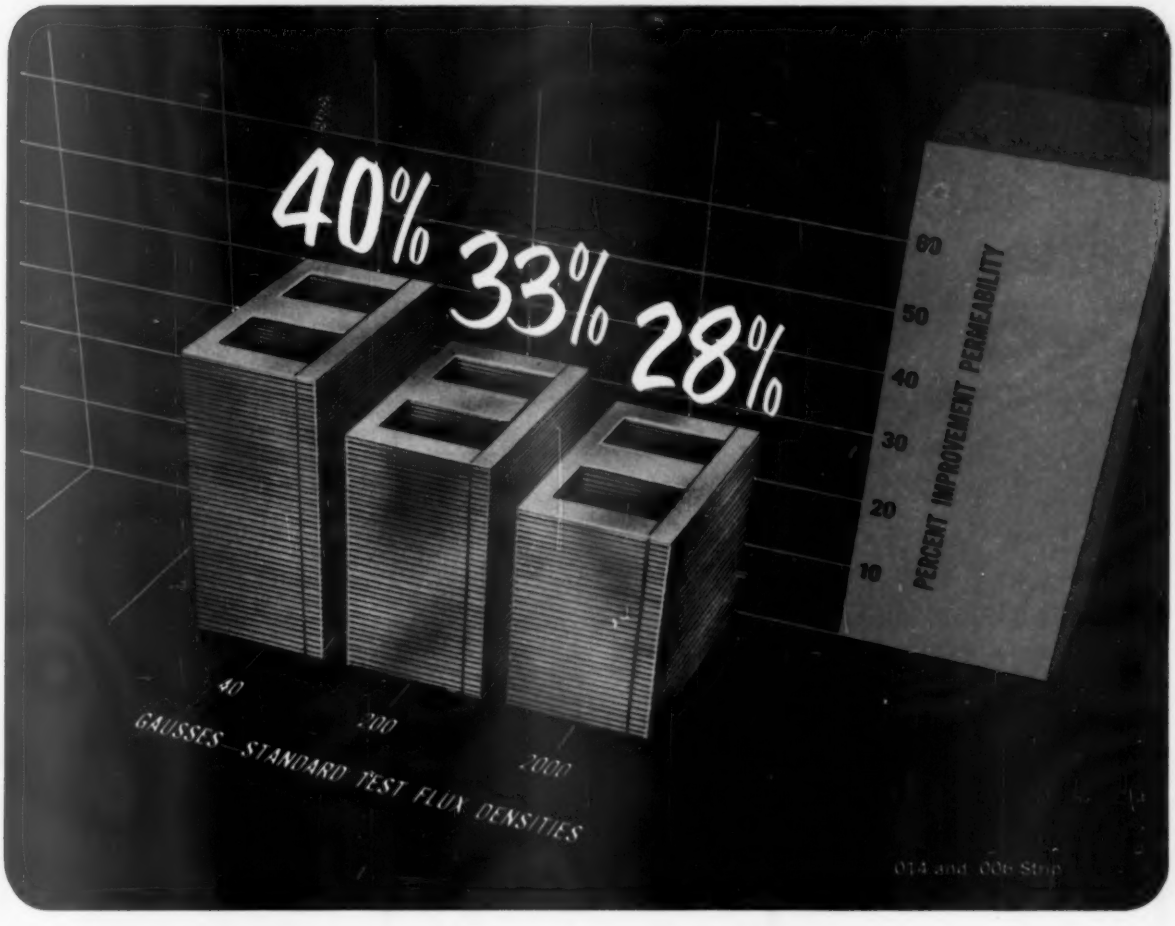

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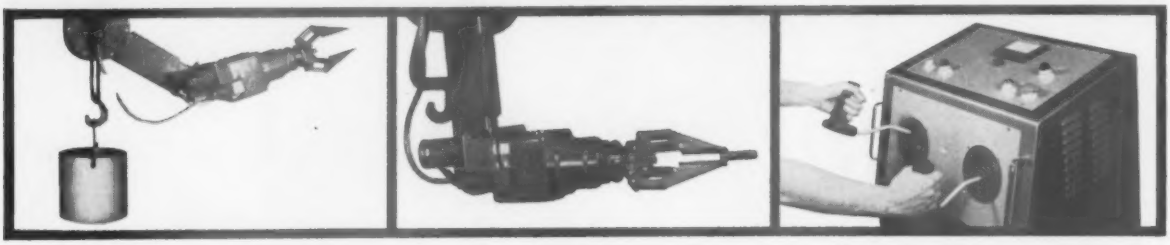

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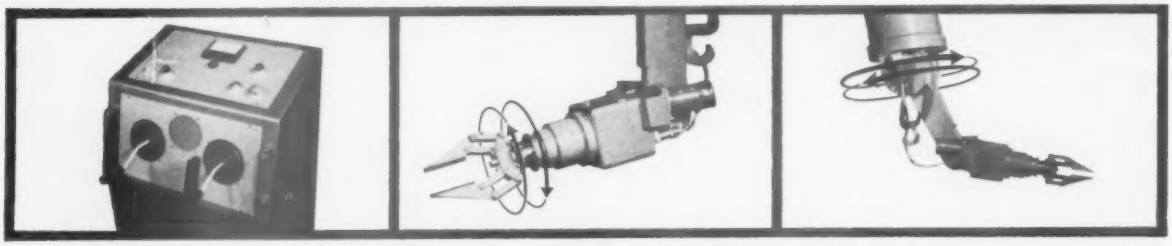

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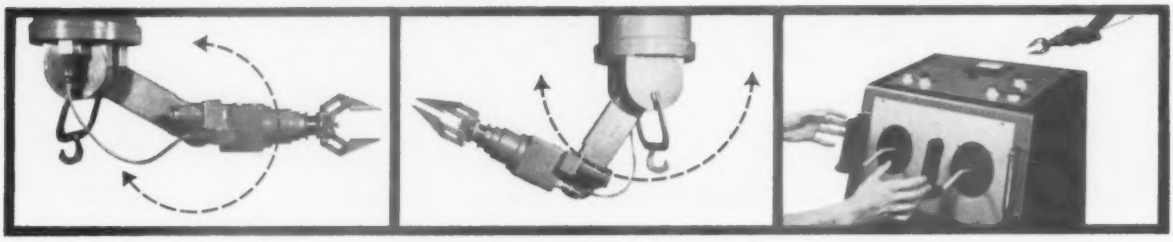

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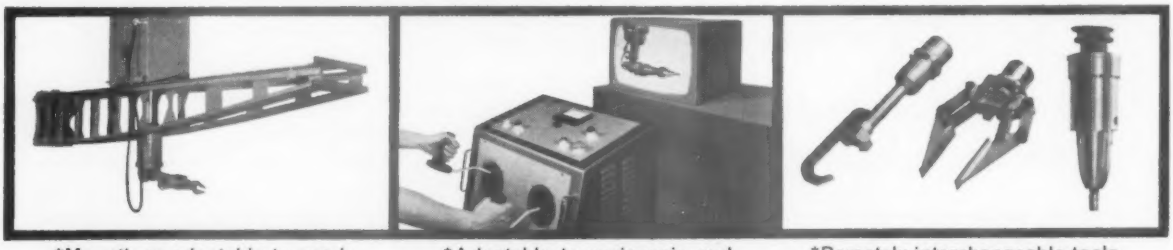

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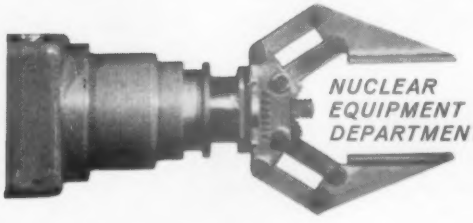

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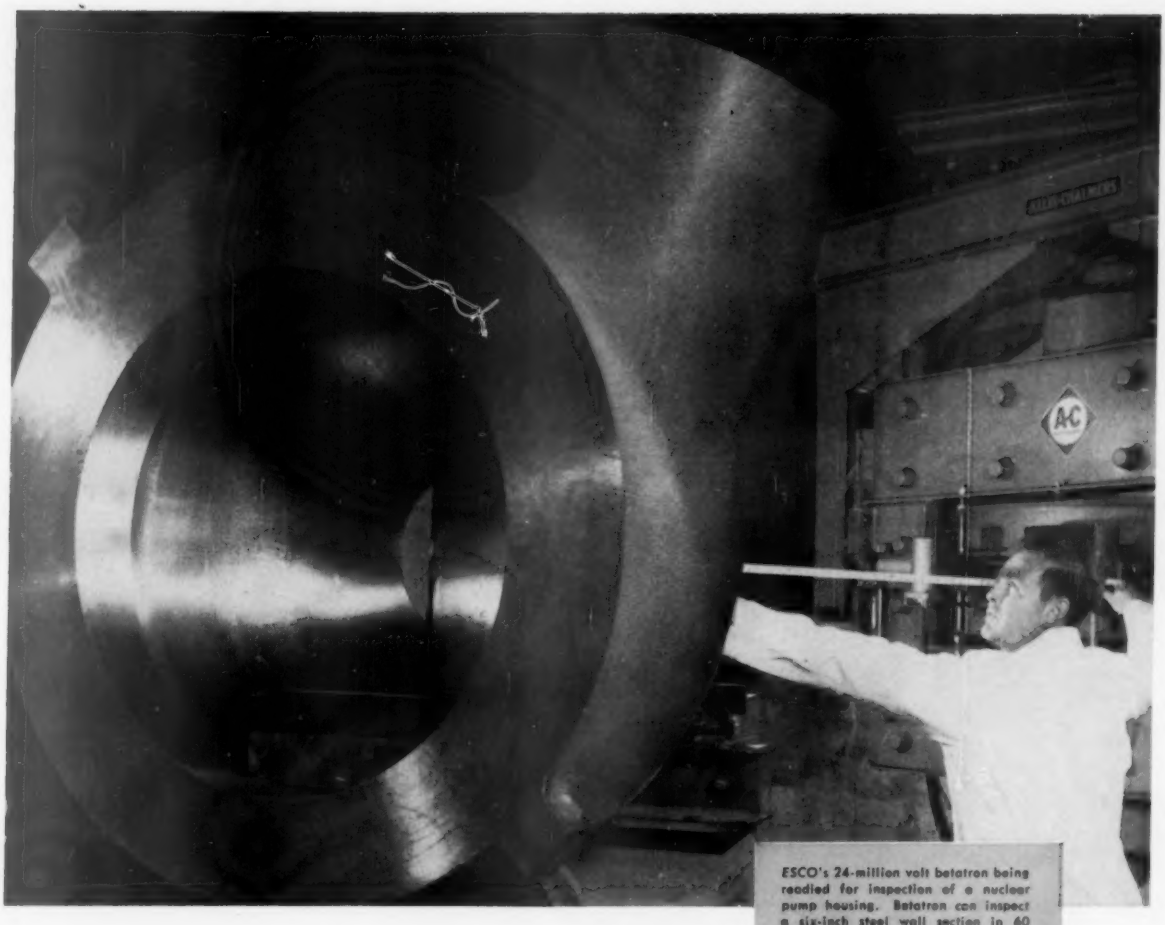

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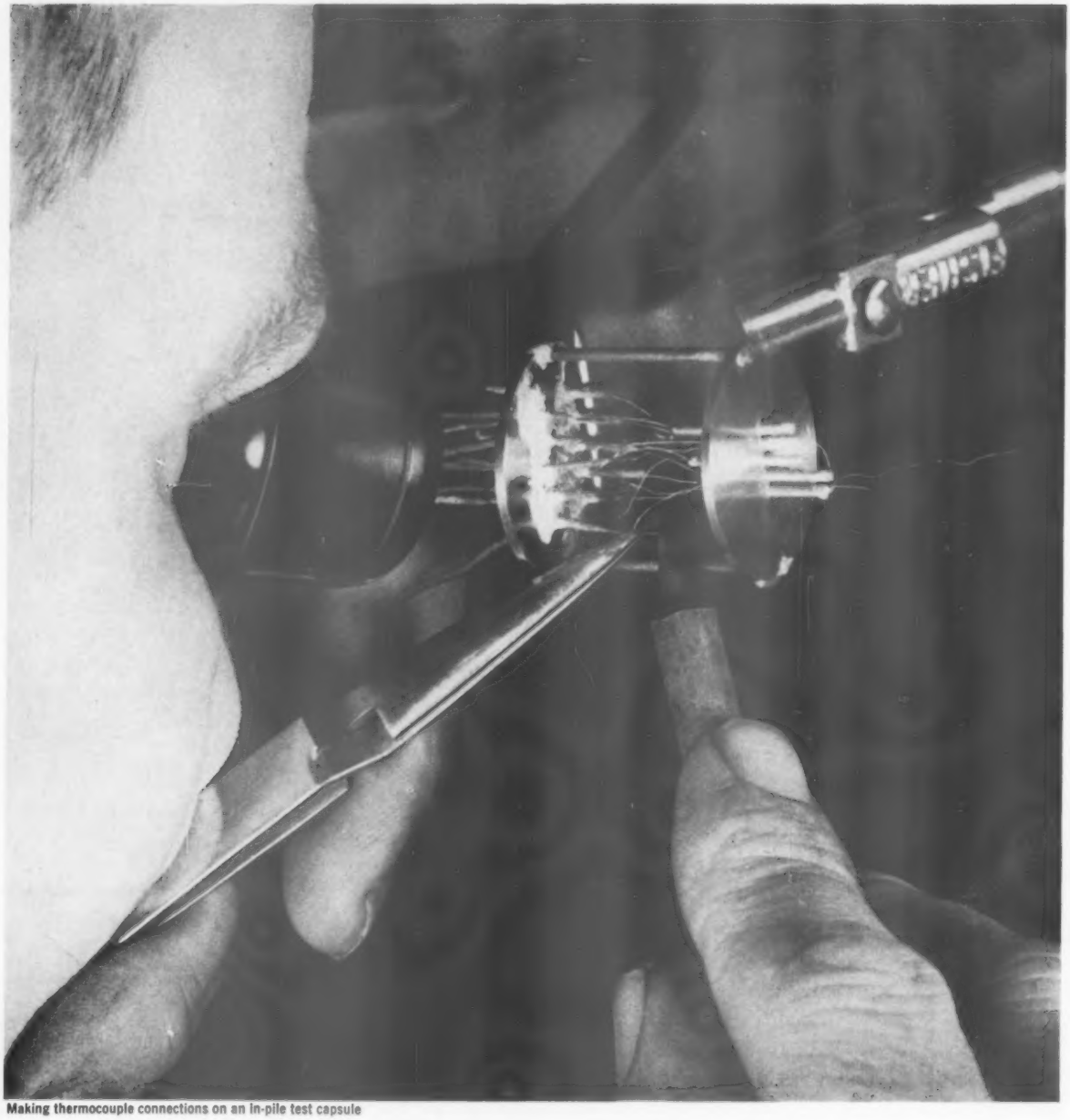

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ROUNDUP of Key Developments in Nucleonics

QM Food Program Challenged on Induced Radioactivity

Mix a little overoptimism with the threat of a public reaction; add an overdose of technical uncertainty and season with just a touch of government bureaucracy. Pop this concoction into the oven of potential political furore and you have the Army's Food Irradiation Program after a six months' exposure to the specter of induced radioactivity.

As an Army Quartermaster Corps official put it last month the program now appears to be "out of the woods." But the discovery by governmental "powers that be" outside of QM that a 24-Mev accelerator ordered for the program would induce some radiation in food had the entire effort on the ropes from January to July. Even in mid-July there remained some unanswered questions about the program's future (When will the $7.5-million food-processing pilot plant at Sharpe General Depot, Stockton, Calif., be given a construction go-ahead? When will construction of the 24-Mev machine be resumed?). But, on balance, the program appears to have survived an extremely rough going-over. This was the situation:

Soon after the adoption last summer of a federal food-additives law for the commercial consumer it became apparent that the military consumer would be involved, as well. A provision of the law bars the use of additives known to be carcinogenic (cancer-producing) and it is generally accepted that induced radioactivity is an "additive" that has this potential.

Surgeon General Objects

The Army's Surgeon General's Office challenged the use of the 24-Mev linac planned for processing at Sharpe, on the ground that some foods irradiated at intensities higher than 10-Mev would become radioactive—though at admittedly low levels. The Surgeon General decided that the military would have to abide by a final decision of the Food and Drug Administration on any irradiated food product and FDA, in turn, was bound by law to rule against any carcinogenic additive.

Accompanying the challenge of the linac was a challenge of the entire food-irradiation program, including the plan to use Hi-Fi, a 2-megacurie cobalt-60 source under design by Curtiss-Wright (NU, July '58, 27). Assuming induced radiation itself was no real practical or technical problem, QM was asked, was it of such a political nature that foods processed at the facility planned for Sharpe Depot could not be fed to military consumers? Would Congress be willing to give FDA special dispensation to okay foods that had been radioactive at some brief period in their processing?

The QM Corps, now in trouble, clamped an "official use only" classification on the subject of induced radioactivity and on plans for the Sharpe facility; this secrecy move took effect last December. Then, the Army hired Stanford Research Institute and Nuclear Science and Engineering Corp. for special study of the induced-activity issue vis-a-vis the Sharpe facility. Late last spring the Army was advised that the linac (already on order from Varian Associates) could be operated at levels less than 10-Mev without inducing radiation; the Hi-Fi had never been seriously challenged.

Most of this activation from an electron beam takes place through the intermediary of neutrons generated when gamma rays from the linear accelerator strike nuclei of the food or its environment. This neutron production is much greater at 24 Mev than at 10 and is virtually absent for cobalt-60 gamma rays.

A QM contractor has since worked up comparisons of exposures to be expected from natural background radiation with exposures possible from the ingestion of food irradiated by the Hi-Fi and the Varian accelerator. His estimates: for natural background an average of 147 milliroentgens/yr (with wide variations from place to place); for Hi-Fi, 0.00000002 mr/yr (2×10^{-8}), or far less than existing instrumentation can count; for a linac operating at 24-Mev, 3 mr/yr—or 2% of background—for a person living entirely on irradiated food.

In May QM agreed to revise its

Physicist tapped to succeed Libby; Graham confirmed

As it did a year ago when it selected a director for the Reactor Development div., AEC last month ended its long search for a successor to Commissioner Willard F. Libby by tapping one of its own people—physicist John Harry Williams, director of the Research div. since April '58. Williams was expected to be confirmed by the Senate—as AEC's lone scientific member—without controversy. Some of his nuclear "credits": '43–'46, Manhattan project engineer; '46–'58, physics professor at Minnesota Univ. and director of the proton linac project; '58–'59, president, Midwestern Universities Research Assn. Earlier, the Senate confirmed John S. Graham for a fresh 5-year term.

AEC to build process-heat reactor for Interior dept.

The Nation's first nuclear-heat plant for distillation of fresh water from sea water will be located in California—one of five plants to be built under the Interior dept.'s saline-water program. Conceptual design of a low-temperature, low-pressure reactor (type undisclosed) has been prepared by Argonne National Laboratory. Estimated cost of the nonnuclear portion of the plant is $1.5-million; $4-million is available for the reactor.

food-irradiation program: 1. The linac will be confined to operating levels less than 10-Mev when used for food. 2. Stockton will be restricted to experimental use (as against the multi-ton-per-day production for which it was designed) pending completion of carcinogenic studies by the Surgeon General and the National Research Council. 3. The human-feeding program, which had been suspended, will be resumed under conditions designed to shed more light on the carcinogenic problem.

What Next?

Where have the gyrations of the last several months left the program? When will the military procure irradiation-processed food as a normal supply item? What does this mean in terms of commercial marketing by the food industry?

Program Status. As of late July QM's funds for construction of the key facility at Stockton had not been released. All QM officials questioned by NUCLEONICS, however, were confident that the money would be made available by early fall at the latest. They estimated it would take 90–120 days to select a contractor and about a year to complete the plant.

Work on the Varian linac that will go into Stockton was stopped when Varian "ran out of money" at the end of fiscal '59. When fiscal '60 funds are released to QM it will undertake negotiations with Varian on resumption of accelerator construction.

As for the Hi-Fi, builder Curtiss-Wright has recommended a final design to QM and AEC (handling the Hi-Fi project for QM) and a go-ahead on this was also expected by early fall. Construction would take a year, or until late 1960.

21 Foods Under Animal Feeding Test

beef	green beans
pork	potatoes
bacon	sweet potatoes
shrimp	flour
codfish	fruit compote
chicken	evaporated milk
tuna	peaches
beef stew	oranges
carrots	jam
corn	chicken stew
	cole slaw

Of the 21 foods making up the Army's program (*see table*), a handful are nearing the end of animal-feeding tests begun several years ago and all should be through this phase of the program within 18 months. However, newly scheduled carcinogenic studies—involving supplementary animal-feeding tests to meet FDA requirements and human feedings for psychological reasons—will take another 2–3 years.

Military Marketing. Thus, it will be 3–5 years before the Army is ready to go to FDA for approval of any irradiated food product. FDA has made it clear to the Army that Congress alone will determine whether irradiated foods may be approved for military and civilian consumption, though the Army is technically free to feed irradiated foods on its own responsibility. Officials close to the Army's program said they expected FDA, once it was satisfied that irradiated foods were safe, to ask amendment of present law to permit the use of specific foods or specific categories of foods. How long this procedure would take is anyone's guess.

Despite the fact that the animal-feeding program is oriented to 21 specific foods, the over-all QM effort has a slightly different orientation. The plan is to perfect potatoes and meats (beef, pork, chicken, bacon) first, then attempt sandwiches, stews and other "dishes," then develop brown-and-serve products.

Commercial Irradiation. The events of the last six months have only served to cement the food industry's decision of some time ago to let the Army take the initiative. Some 40 of the 100 industrial and research organizations active in the program are absorbing most of their own expenses but all of their work is for the Army program. Coordinator of technical activity is the QM Food and Container Institute in Chicago.

"To do research in this area," an industry official said, "is very expensive and industry just doesn't want to spend so much money on something that is not a sure bet.

"I think industry is very interested in the program as a whole but I think also that industry is discouraged because it's taking so long. However, we can't afford to step things up ourselves, so we just have to wait. For example, Swift & Co. tried to do some food irradiation work on its own and spent a fortune renting an accelerator. But they found, like many others, that it's a tough problem.

"Now they're just like the rest of us and waiting to see what's going to happen."

Once the Sharpe facility demonstrates the feasibility of food processing the food industry will pick up its historic function as the military's supplier, using techniques demonstrated at Sharpe.

QM and industry officials alike lay emphasis on the potential of pasteurization—rather than sterilization—for both military and commercial processing of food. Extension of shelf-life by a week or more for many foods can be accomplished with irradiations of 50–500,000 rad—far below the threshold for affecting taste, texture, color and odor, far below the 2–5-megarad dose required for sterilization.

At sterilization doses, some foods undergo strong flavor changes (notably beef); others are discolored; fruits and vegetables are subject to textural changes; and, finally, there are enzyme and chemical reactions during storage of some irradiated foods. None of these difficulties shows up at doses required for pasteurization.

Army Reviews Food Irradiation—A Report to JCAE*

1. *There is not a measurable amount of radioactivity induced in food irradiated by a 6-megarad dose with cobalt-60.*
2. *It is possible to induce radioactivity in foods with a high energy electron beam and with [spent] reactor fuel rods.*
3. *Amounts of radioactivity in certain foods have been calculated from measured amounts in food salted with larger quantities of critical elements and irradiated with a 24-Mev electron accelerator at a 5-megarad dose.*
4. *Radiation effects of certain elements, small as they may be, are additive in the body. Thus, provisions of [the food additives] law appear to apply.*
5. *Proper radiological control can assure that dosages due to induced radiation are orders of magnitude below levels that expert opinion regards as biologically tolerable.*

* Excerpts from a letter of June 4, 1959, from Gen. Herbert Loper, assistant secretary of defense for atomic energy, to the Joint Committee on Atomic Energy reporting on review of the QM Food Irradiation Program.

House Okays AEC Appropriation Bill for Fiscal 1960

A $2.3-billion AEC appropriations bill for fiscal 1960 was approved by the House and its Appropriations Committee last month and sent to the Senate. Highlights:

- The House reduced AEC's requested amount by $43-million, including $10-million sought for physical research, $3-million for the Isotope Development Program and $2-million for Project Plowshare.
- Another $10-million was lopped off the Reactor Development Program—$2.5-million asked to close out the liquid-metal-fueled and molten-salt programs; $2.2-million cut out of the $17.7-million requested for general reactor research; a reduction from $11- to $10-million in the Army Nuclear Power Program; and a reduction from $68.7- to $65-million in the Aircraft Nuclear Program.
- $3-million was added to the program for design and advance procurement for a nuclear superheat reactor prototype. AEC did not request these funds but indicated it might be in a position to use them late in the fiscal year.
- $3.1-million requested by AEC for reactor equipment grants to colleges and universities was reduced to $1.8-million; the Appropriations Committee suggested that education increase its own investment in research facilities.
- The $3-million reduction in isotope development funds was less than half the requested total of $6.2-million. The Committee (*see page 27*) said it felt "that since the benefits derived from this work will ultimately be in the form of substantial money savings in industrial processes, it can be reasonably expected that industry will shoulder most of the development and training costs incident to the use of isotopes."

LATE & MISCELLANEOUS

ANP Illness Diagnosed: Hardening of Fund-Artery

Basic conclusion developed at last month's Congressional hearing on the Aircraft Nuclear Program—first ever in public—was this: While top Air Force and AEC officials want to start construction of an early-flight prototype plane, this could be done only at the expense of other Pentagon research and development programs. The nuclear plane, long a glamor project in the atomic world, rates lower priority in the over-all scheme of things, because the Administration's scientific brass is disenchanted with the project's potential and the distance still to be covered to get the desired weapons system.

Suisatom Asks Go-Ahead

Suisatom has asked Swiss authorities for permission to begin construction of its long-planned 20-Mw(e) boiling water reactor at Villigen in northern Switzerland, near the Würenlingen nuclear research center. General Electric would provide the reactor, but a major part of the equipment would come from Swiss industry, including a Brown Boveri turbogenerator set. Capital cost is estimated at $14-million, operating cost at $2.5-million/yr, power cost at 25 mills/kw at the outset, 20 mills when power is raised to 27 Mw(e) after two years.

2 Reactors Go Critical

A French and a German research reactor went into operation last month. France's Triton, a 1.2-kw swimming pool for shielding studies, went critical at the Fontenay-aux-Roses research center. It is similar to Mélusine at Grenoble. West Germany's fifth research reactor and first to be produced domestically is an Argonaut-type at Garching near Munich, designed and built by Siemens-Schurkertwerke. First privately-owned reactor in Germany, it will be used in Siemens' design work on heavy water power reactors.

2 Nuclear Ships Launched One Week Apart in U. S.

The U. S. last month launched its first two nuclear surface ships within one week of each other. On July 14 Bethlehem Steel's Quincy, Mass., shipyard christened and floated the world's first nuclear surface fighting ship, the Navy's guided-missile cruiser U.S.S. *Long Beach*—14,000 tons, two Westinghouse pressurized-water reactors. On July 21 New York Shipbuilding Co. at Camden, N. J., sent the world's first nuclear merchant ship down the ways: N.S. *Savannah* is 10,100 displacement tons light, has one Babcock & Wilcox pressurized-water reactor. She will be operated for the Maritime Administration by States Marine Lines. Both ships are expected to start sea trials next summer.

(The world's first nuclear surface ship, the Russian icebreaker *Lenin*, was launched Dec. 5, 1957, and was to have gone into service by end of last year. Russian atomic energy officials queried last month said she will go to sea "sometime this year.")

Now: Boiling Sulphur Reactor

AEC has accepted, as a basis for contract negotiations, a proposal for a study on a new reactor concept: the boiling sulphur reactor, offered by Aerojet-General Nucleonics. The concept holds promise of attaining high thermal efficiencies if engineering problems can be solved. The nine-month-study proposal was picked from 11 unsolicited proposals submitted between Sept. 1, 1958 and Feb. 28, 1959.

ICSE to Replace Zeta

The British are planning a new pinch-effect experimental facility to replace Zeta (NU, Feb. '58, 90). Called ICSE (for Intermediate Current Stability Experiment) the $1.4-million toroidal device will have ten times the pinch current and 100 times faster rise time than Zeta. More importantly, pinch current will be in one direction on the axis of pinch, in the opposite direction on its sheath. Theory says that such a current configuration should eliminate the plasma instabilities that now plague Zeta. ICSE will test that theory.

Spevack Gets D_2O Patent

U. S. Patent No. 2,895,803 was issued to Jerome S. Spevack last month, bringing to an end his long fight with AEC over public disclosure of his improved process for the production of heavy water (NU, Jan. '59, 26). Estimating that he could produce D_2O for $9–10/lb—AEC's current price is $28—Spevack was looking for someone to invest $10-million in a commercial facility.

Todd to Build Savanah Barge

Todd Shipyards' Houston, Tex., division has received a contract—as low bidder at $569,165—to build a nonpropelled shipside nuclear service barge to maintain, refuel, and handle waste-disposal operations for N.S. *Savannah* and other nuclear-powered ships. The 129-ft, 650-ton barge was designed by Electric Boat division of General Dynamics.

ROUNDUP

AIF Remolds Itself to Rally Nucleonics Industry

The six-year-old Atomic Industrial Forum is being remolded to bring to bear upon government policies and major problems of the nucleonics industry the fullest possible force of industry opinion and concerted action. Under the purposeful hand of General Electric's Frank K. McCune, elected to the Forum presidency last year, the Forum:

1. Will retain its historic function as a clearing house for exchange for both technical and nontechnical information, but

2. Will go well beyond this function with a "major program" oriented to solution of such cross-industry problems as AEC contract and patent practices, revision and enactment of legislation, statistics and standards for the nucleonics industry, activities of the national laboratories, and AEC's price and cost practices.

3. In addition, McCune has appealed to the presidents of each of the member companies to speak out on regulations and legislation.

McCune

"It is perhaps a popular and understandable misconception," McCune said in his special appeal to company presidents, "that only technological problems stand in the way of bringing into realization a strong and vigorous atomic industry. A no-less-important misconception is that participation in relatively specialized and isolated areas of atomic energy development absolves organizations in those fields of any responsibility in the formulation of public policy.

"On the contrary, the atomic industry is perhaps unique in that its future is as dependent upon finding workable solutions to problems of national policy as finding solutions to scientific and engineering problems. Both will require the continued attention of a broad cross section of top management if industry is to make a maximum contribution to the rapid development of atomic energy."

Decisive Industry Role

There is thus emerging at 3 E. 54th St., New York City, a Forum determined to see that the nucleonics industry has a more decisive influence than it has now in the regulatory climate under which it will operate for many years to come. The "new" Forum has stopped short, however, of a position as "spokesman" for the industry.

"To those who may wonder why the Forum has not undertaken the responsibility to represent the atomic industry on the Washington scene," McCune said in his letter to the chief executives, "let me say that I do not believe that we can or should, as some associations do, voice an authoritative opinion as being that of all Forum members. As I explained to JCAE Chairman Sen. Clinton P. Anderson [D–N. M.] earlier this year in response to an invitation to the Forum to testify during the Section 202 Congressional hearings, the Forum has not attempted to influence or determine the attitudes of its membership.

"Rather, the Forum has attempted to conduct investigations and studies, to hold forums at which important and timely subjects can be discussed, and to otherwise provide a means for assembling factual information and informed opinion which, in turn, is made available to its members as well as to the public."

McCune pointed out that this reluctance of the Forum to don a spokesman's mantle did not preclude its taking "a more active role" in regulatory and legislative matters. First, the staff has been directed to continue its close work with the staffs of AEC and JCAE and to step up its efforts to keep Forum members advised of proposed AEC regulations, JCAE hearings, etc.

Secondly, both staff and officials of the Forum will probably increase personal contacts with AEC and JCAE people on industry problems. The Forum board of directors met with the Commission and members of JCAE in April to outline the new Forum program, and other such meetings may be held periodically.

Thirdly, the Forum, under the aegis of its program committee has scheduled eight "problem areas" for special study—either by an ad hoc committee formed for the purpose, by an individual member or by an existing committee (*see box*). A ninth—competitive activities of the national laboratories—had been tentatively scheduled for study but was indefinitely postponed because JCAE hearings are slated next year (NU, July '59, 21).

Forum is Investigating Eight Problem Areas

International Liability. Jose de Cubas, Westinghouse, heads a 10-man group "to take whatever action is necessary" to further U. S. industry's interests; meetings have been held with Euratom and the Organization for European Economic Cooperation.

AEC Contract Practices. An outside expert will analyze this problem in cooperation with the Forum committee on legal problems.

Uniform Bases for Reactor Cost Analysis. Titus G. LeClair of Commonwealth Edison heads a 4-man group working on a cost system.

Government Price and Cost Setting. Former AEC General Manager Kenneth D. Nichols will study this and related financial matters such as capital subsidies for power reactors.

Legislation and Regulation. Frederick L. Hovde, president of Purdue Univ., will direct a study on desirable legislation.

AEC Patent Practices. First step in a study by AIF's patent subcommittee has been circulation of a questionnaire to members.

Nuclear Standards. Robert L. Wells of Westinghouse is the new chairman of AIF's committee on standards; Forum participation in standards activities will be increased.

Industry Statistics. A public accounting firm has been retained to compile statistics on: sales and orders of nuclear systems, components, materials and services in '58; total sales '54–'58; research-development spending '54–'58; capital spending '54–'58; and employment in '58. The census will be renewed annually.

AEC, Industry at Odds On Site Safety Criteria

AEC has evoked an outburst of industry indignation in its first attempt to take some of the judgment factor out of reactor-safety evaluation (NU, July '59, 21). Vigorous demands for more time to prepare industry comments on proposed site criteria, plus comments received even before the deadline was extended for 60 days to Aug. 24, have made it clear that AEC has a bear by the tail.

Virtually all of the "early returns" from industry lauded AEC's over-all goal—safety criteria to guide applicants for AEC licenses—but the opinion was near-unanimous that reactor technology was not sufficiently advanced to permit adoption of standards now.

Typical was the comment by Chauncey Starr of Atomics International: ". . . hurried enactment of regulations could effectively smother the infant nuclear industry." Starr said premature action not only could stunt growth in this country, but could inspire similar action in heavily-populated Europe, thus reducing the potential market for American equipment firms there.

His and other industry complaints centered on these points:

• The **proposed exclusion area** (¼ to ¾ mi) was unrealistic since reactors typically are built on rivers or other bodies of water which the reactor operator cannot possibly control. To move the reactors away from the water would be uneconomic.

Atomic Power Development Associates of Detroit said such a regulation would "exclude most power reactor sites in the United States."

Pacific Gas and Electric Co., among others, questioned whether an exclusion area of a specific size was necessary for proven, as contrasted with unproven, reactor types.

• The **population density** proposal ignores the fact that the reactor operator has no control over the changing population surrounding his plant. And, in the view of several industry respondents, population density cannot be considered apart from containment and other safety factors. Thus, no rigid standard should be set.

"Until comparable operating characteristics of different reactors are better understood," was one argument, "it would seem to be impracticable, unwise and damaging to sound evaluation of reactor technology to establish quantitative site criteria by regulation."

The American Public Power Association said the population proposal could "result in restricting the use of nuclear power stations to a relatively few large utility systems in the country. It could limit very seriously the generation of nuclear power by municipally owned electric utilities or other utilities serving areas of limited size."

The APPA noted that AEC has already approved sites which do not meet the proposed standards—namely the Power Reactor Development Co. reactor near Monroe, Michigan, the National Aeronautics and Space Administration's testing reactor near Sandusky, Ohio; and the Piqua, Ohio, power reactor.

Several of the companies expressed fear that setting a general but not mandatory standard in terms of miles from populated centers would lead to public concern when a reactor was approved for construction closer to the centers.

"Interpreted literally," commented the Massachusetts Institute of Technology, "this requirement would preclude construction of power reactors where they would do the most good economically."

Harold Price, AEC director of licensing and regulation, emphasized that the May announcement did not constitute a proposed rule as such, and the factors enumerated would not become governing until such time as a formal regulation is issued. The idea, he explained, was to stir thinking on the subject, and to start laying the groundwork for safety criteria.

Euratom to Take Over Ispra, Two Other Labs

For its Common Centers of Research, Euratom has decided—instead of starting from scratch—to take over three laboratory complexes already well under construction. Ispra in Italy will be the largest, backed by Petten in the Netherlands and Karlsruhe in Germany. Euratom's Nuclear Measurements Center at Mol, Belgium, will be maintained there.

"Research is the pillar of Euratom" is the new watchword as this redoubtable array of research organizations is knit into one network. As a matter of fact, Euratom is presently being encouraged to think less about power and more about filling in the gaps in nuclear knowledge.

In Ispra, Euratom takes over a fair-sized facility with a brand-new, 5-Mw CP-5 type heavy-water research reactor that went critical in April. Ispra is being taken over—under terms of an agreement subject to approval by Rome—at a "symbolic" rent, on a 90-yr lease. Another part of the bargain is that Italy will provide $10-million worth of staff housing and a "European school" such as already exist at Brussels and Luxemburg. Staff is expected to be 200 by year's end. Most of the Italian workers already there will be integrated into the Euratom complex as the existing Ispra organization is absorbed into the Euratom program.

Present planning calls for $40-million contribution by Euratom to Ispra, with $15-million more coming from the Italian government, and a target of 1,200 staff by end of 1962. Petten will get $16-million from Euratom, an amount not yet fixed from the Netherlands government, and should have 400 staff by end of 1962. Details concerning Karlsruhe are still under negotiation.

Petten's function will center mainly on its high-flux materials-testing reactor, now nearing completion. Karlsruhe, where West Germany is building its first all-German-designed research reactor, is reportedly going to concentrate on plutonium work. Ispra will do practically everything else, and will thus be principal spender of the $215-million programmed for research in the Euratom Treaty appendix. Included will be neutron and solid-state physics, metallurgy and reactor physics. Ispra will also be the main research documentation center and will house a microfilm library presented to Euratom by AEC; and it will be the main Euratom center for specialized training. Petten will offer courses for about 100 trainees from non-Euratom countries.

Ceding Ispra to Euratom will not slow down Italy's national program. Part of the Ispra program will be absorbed by the Casaccia Nuclear Studies Center near Rome, where Italy's CNRN (National Commission for Nuclear Research) is setting up a General Atomic Triga reactor. In addition, CNRN plans to build a new experimental reactor in collaboration with Italian industry.

AEC in Embarrassing Squeeze on Test Reactors

On Nov. 8, 1956, AEC issued this policy declaration: "AEC is looking to private industry for the construction and operation of general purpose test reactors to meet growing needs of the Commission in its reactor development program and those of private industry in the development and construction of nuclear power plants."

"To encourage private enterprise to enter this phase of the atomic industry," AEC promised, "the Commission will construct test reactors only if its needs for irradiation space cannot be met by private industry under contracts reserving for government use a percentage of the space available in privately-owned test reactors."

Not quite two years later—on Oct. 2, 1958—AEC implemented this policy declaration of November '56. Its invitation to industry to bid for five-year space contracts brought proposals in January from six firms or groups offering to build new reactors and four owners of existing reactors, including General Electric (GETR) and Westinghouse (WTR) (NU, March '59, 24).

Last month, AEC had reason to ask itself, "What monster is this we have created?"

For the Commission had made the disconcerting discovery that its own best interests and those of the taxpaying public appeared to lie in rejecting all industry proposals for construction of new test reactors—in favor of a new reactor of its own.

Moreover, AEC officials were soft-pedaling plans to lease space in existing reactors because: 1. promises to give business to GE, Westinghouse and others might prejudice chances of getting the lowest possible prices; and 2. the Commission is wary of "bail out" charges on these privately-built facilities.

'We Build, You Operate'

In a nutshell, the dilemma was this: industry sponsors of new reactor facilities—with very few exceptions—were demanding five-year contracts large enough to cover all or most of the capital cost. As a member of AEC's contract selection board protested to one of the proposers, "We [AEC] are going to build the machine and you're going to operate it."

At the end of the five-year period, such AEC-supported reactors would be privately owned and available to the customers willing to pay the highest price. Variations were offered—for example, one industry group offered AEC an option on a second five-year period at sharply lower charges than the first—but it soon became clear to the selection board, and many of the proposers themselves, that it would be much cheaper for AEC to build a reactor which would be available for government use 20 years or more.

Industry's position was that it was not prepared to commit capital to a test facility for which it could not be assured of business beyond the first five years of operation. For proposers raising their own construction money, it was a case of capital priority—they have more lucrative employment for their money unless AEC guarantees "a five-year payout." For proposers borrowing money, as one industry observer noted, "there's not an outfit in the U. S. willing to lend money for a test reactor without getting a contract guaranteeing the loan."

AEC Requirements

There was no question in anyone's mind—either in industry or at the AEC—that more reactor test space is needed. Authoritative sources put the foreseeable need at seven loops at least for the Naval Reactor Program, four or more for the Fuel Cycle Development Program, and 15 for the civilian and Army reactor programs (*see box*).

Most of the current requirement is met by the reactors at the National Reactor Testing Station—the huge Engineering Test Reactor (ETR) and the much smaller Materials Testing Reactor (MTR) but ETR will be available for only six weeks through the rest of '59 because of experiment installation.

Much of the Naval requirement is for high flux space—both fast and thermal—which AEC people say that GETR and WTR cannot handle. GETR is operating two Oak Ridge-supported loops (gas and capsule) and is continuously talking with AEC contractors for more AEC-funded business. WTR has only just gone on the line (June 29) but is understood to be virtually assured of three loops—Carolinas-Virginia Nuclear Power Associates, East Central Nuclear Group/Florida Nuclear Group and a water loop for the Air Force reactor for Sundance, Wyo.

GE and Westinghouse are seeking long-term contracts from AEC under the test-reactor program but negotiations have been held up pending a final Commission decision on a new reactor. GE officials said they were looking to the government to take about half of GETR's space; Westinghouse officials make no bones that "commercial business doesn't amount to anything—the real business is fuel testing and almost all of that is government supported."

Power-Reactor Space

Another AEC-sponsored space-leasing proposal—rental of space in full-scale power reactors such as Dresden (NU, Aug. '58, 79)—has not gotten off dead center. Talks with utility reactor sponsors last fall turned up these objections: research-and-development programs would interfere with power operation; regulatory bodies would look askance at a rate structure influenced by extensive experimenting; and testing of experimental fuel elements would fog guarantees on a reactor's own core. Talks have not been resumed.

When and if the air is cleared on the test-reactor problem, AEC is expected to designate Idaho Operations Office as a center for government-funded test-reactor services. Idaho would channel all work to given reactors and police space rates and contract terms.

B&W Winning Bidder

As NUCLEONICS went to press it was learned on high authority that AEC had decided to accept the test-reactor proposal of Babcock & Wilcox as a basis for negotiation of a five-year contract. B&W proposed a 60-Mw, variable-power reactor (4 x 10^{14} flux) to be built near Lynchburg, Va., in 18–24 months. The reactor would meet low- and mid-flux needs; AEC has begun design of an advanced, high-flux test reactor.

15 Prospective Loops

Army program—liquid metal
Army program—gas
Phila. Electric—gas
Carolinas-Virginia—water
Florida project—gas
Northern States—water
Gas-cooled Reactor Expt.—gas
Fast-breeder (2)—sodium
Merchant ship (Gen. Atomic)—gas
Euratom (2)—water
T-7 tanker (2)—water and gas
Sundance (Air Force)—water

Reactor News

CANDU INTO CONSTRUCTION PHASE

Final design is underway on the Canadian Deuterium Uranium reactor (CANDU)—a 200-Mw(e) improved scale-up of the 20-Mw(e) Nuclear Power Demonstration reactor now under construction at Des Joachims, Ont. Atomic Energy of Canada Ltd., which started feasibility work on CANDU in 1957 intends early construction of the $60-million plant, at a still-undetermined site, for operation in late 1964 or early 1965. Like NPD, CANDU will use a heavy-water–natural-uranium (75 tons) system. Also as with NPD, Ontario Hydro will provide a site, collaborate in design and construction, and will operate the station. In addition it will purchase CANDU after the plant has demonstrated suitable characteristics for Hydro's power system. The formula for the purchase price will permit power production at competitive cost.

KIWI-A SUCCESSFULLY TESTED

First unit in Project Rover (AEC's nuclear-rocket program), the Kiwi-A reactor was taken to power for the first time at the $10-million desert facility at Jackass Flats, Nev., on June 20. The machine (photo NU, Jan. '59, 27) was run at power with all systems operating for 5 min after several hours' warmup. After a number of power runs with varying combinations of subsystems in operation, the test program was completed July 1. Kiwi-A is now being dismantled for study and evaluation. Its core is believed to have attained temperatures in the range of 3000° F; hydrogen passing through it expands suddenly to provide thrust. During the tests, Air Force bombers took air samples above the reactor, which was remotely controlled from 2 mi away. More advanced models, dubbed Kiwi-B, Dumbo and Condor, are being worked on at Los Alamos Scientific Laboratory.

PRTR ENTERS FINAL BUILDING PHASE

Final stage of construction has begun on the Plutonium Recycle Test Reactor at Hanford. The $15-million unit is to be completed by next spring; an associated fuel-element-fabrication pilot plant costing $4-million will be ready this September.

NUCLEAR-IONIC SPACE PROPULSION PROPOSED

Three Lockheed scientists have proposed a nuclear-ionic propulsion system for spacecraft "within our technical capacity." The system involves direct conversion of nuclear power to electrical energy for an ionic low-thrust engine. Ion-propulsion unit and a passenger cabin will be separated from the reactor by a mile-long coaxial cable "subject to only small stresses in the gravity-free environment." The 1-Mw(th) reactor, fueled by 200 kg U^{235} in fully-enriched uranium carbide, would provide power for a thrust of 0.001 g, sufficient in outer space to propel a big spacecraft. The core, which would allow 1 yr of full-power operation, would be housed in a larger cylinder 4 ft long by 2½ ft dia whose shell would contain 200 thermionic converters. These would generate a total of 100 volts from the electrons boiled off by the reactor's 3860° F heat.

SRE MAKES 1000° STEAM

In the race for nuclear superheated steam, the Sodium Reactor Experiment went out in front with production of superheated steam at 1000° F, highest ever produced from a reactor. The achievement came during a routine power run. Sodium coolant temperature leaving the reactor was 1060° F, heating sodium in the intermediate loop to 1040° F; the amount of superheat was more than 500°. SRE has made 15,355,000 kwh for Southern California Edison customers since July 1957.

SPANISH PANEL LEANS TOWARD OMR CONCEPT

The Spanish government has been asked by a government-industry panel to accept an organic-moderated test-and-power reactor proposed by Atomics International (NU, May '59, 34); GE and Westinghouse have also bid.

PHILIPPINES TO GET RESEARCH REACTOR

A 1-Mw pool-type research reactor will be installed at the new atomic research center being built at the Univ. of the Philippines at Diliman, Quezon City, 8 mi NE of Manila. General Electric will supply the $500,000 reactor, slated to begin operation in the fall of 1960. It will be designed for subsequent expansion to 3-Mw operation. The U. S. is underwriting the entire cost of the reactor and will lease fuel.

AI DESIGNS OMR TANKER PLANT . . .

An organic-moderated-and-cooled reactor propulsion plant for a 60,000-ton deadweight tanker has been designed by Atomics International for AEC, to determine specifications and operating characteristics for a reactor of that type to provide 30,000 shp.

. . . AND STARTS ORGANIC CRITICAL

An organic-moderated critical assembly was started up at AI's field laboratory in the Santa Susana Mts. 30 mi NW of Los Angeles. Intended as an aid in design of organic power reactors, it will be used first for experiments for the 11.4-Mw(e) Piqua organic reactor.

AEC HEARS DRESDEN, OKAYS CON ED SPHERE

Following a hearing in July, AEC was considering a 40-yr operating license, expiring May 4, 1996, for Commonwealth Edison Co. of Chicago for its 180-Mw(e) Dresden Station, now scheduled to go critical in October. . . . AEC also approved the technical specifications for the spherical steel containment shell for Con Edison's Indian Point, N. Y., power reactor. The sphere, 160 ft in dia of 1½-in. carbon steel, is in turn completely enclosed in a separate concrete structure 5½-ft thick (average). This arrangement elicited praise from the Advisory Committee on Reactor Safeguards: "it will provide the most nearly complete containment presented to the Committee in any reactor project to date."

DETAILS ON NEW MICHIGAN BOILING UNIT

Slightly enriched uranium-dioxide pellets in zircaloy tubes have again been chosen to fuel a power reactor, this time the 50-Mw(e) Consumers Power Co. of Michigan boiling-water reactor to be built at Big Rock Point, Mich. (NU, July '59, 20); 88 fuel elements of 100 rods each will comprise the first charge. The forced-circulation reactor will operate at 1,000–1,450 psi; steam conditions at the turbine will be <1000 psi, 593° F. Containment shell will be a 151-ft-high, 90-ft-dia steel capsule.

NO DISMANTLING FOR X-10

The X-10 graphite reactor, which is to be Wigner-annealed for the first time, will not thereafter be dismantled, as NUCLEONICS stated last month. "This oldest of all operating reactors continues to be a reliable and useful workhorse upon which many important programs depend," ORNL director Alvin M. Weinberg declares.

ROUNDUP

German Power Reactor Progress Still Hesitant

BONN

Only a few of the hopes kindled by the German power reactor program have so far reached a stage close to materialization; the acceleration expected nine months ago has not appeared.

The program announced in December 1957 calls for 4–5 power reactors totaling 500 Mw(e) to be completed by 1965, and the agreement between the U. S. and Euratom, it was generally believed, would result in addition of two more power reactors totaling about 250 Mw(e) in West Germany.

Today there are four groups of public utility companies plus two individual utilities that are considering building power reactors, but progress has been so slow until now, and some of the plans still seem to be in such an early stage, that most observers fail to see 6–7 full-scale power reactors feeding German grids by 1965.

So far, no order for a full-scale power reactor has been placed. Latest developments make it appear likely that the only order expected this summer—by the Southwest German group AKS—may be postponed by at least a year. AKS is the only group that wanted to skip the pilot-plant stage and go to full scale right away. It informed Euratom that it is interested in a U. S. reactor to be completed by 1963, and it has even decided on the type it wants. But difficulties have arisen, and negotiations may take another 4–6 weeks.

Only One Being Built

The only power reactor under construction is still the 15-Mw(e) pilot boiling-water reactor at Kahl being built by AEG and General Electric for RWE (80%) and Bayernwerk (20%) jointly. It is to be completed next summer or fall (NU, July '58, 26; photo, July '59, 26).

A second 15-Mw(e) reactor is about to be ordered by the Northwest German group AVR from Brown Boveri Co. and Krupp. AVR expected that the contract will be signed in about a month. This pebble-bed reactor (once on the point of starting construction, a year ago: NU, Aug. '58, 26) will cost $9.5-million and will be built at the Rhineland-Westphalian research center at Jülich for 1962 completion.

The other projects are still not yet out of their wait-and-see phase. RWE has acquired a site near Augsburg for its long-planned 250-Mw(e) plant; but it has said repeatedly it would buy only when nuclear costs become competitive. Bavaria's group Atomkraft Bayern has given Siemens a design order, for a 100-Mw(e) reactor using pressurized tubes, D_2O moderator, natural uranium and an undetermined coolant, and no action is expected before its completion in 1961–62. The same goes for the Hannover group SKW, which has two design studies underway for it at AEG and Deutsche Babcock. The Berlin utility BEWAG joined the potential buyers, but its plans are in an embryonic stage.

Over-all Considerations

Both the German Atomics Ministry and the nuclear industry have stressed time and again the need for building reactors, even though an energy gap may come only in the not-so-near future. Their reasoning is that experience in the nuclear field is absolutely necessary for an industrial nation because the solution of technical problems in the atomic field promotes new developments essential for many other industries (heavy machinery, control engineering, etc.). And not being up to date in new techniques would prove fatal especially for an industrialized country as dependent on exports as Germany, they argue.

The comparative slowness of progress during the last 18 months has several reasons. For one, energy consumption has fallen considerably short of predictions so that RWE, and possibly some other utilities as well, have actually cut their long-term expansion programs for conventional power plants. Other reasons for foot-dragging are the towering pithead stocks of coal and the absence of a German atomic law, awaited for years, which cannot pass parliament before this fall. But the main handicap is financial.

Compared to other nations with nuclear ambitions, governmental assistance is comparatively small. German governmental funds for backing nuclear progress in 1959 totals only $50-million, including 30% of Euratom costs and projects that Germany has to shoulder.

For the past few years, Germany's nuclear industry has been spending an estimated $6-million annually out of its own pockets on nuclear research and development. About half goes for salaries. Siemens, AEG, Brown Boveri, Deutsche B&W and Interatom have by now received design study or even smaller construction orders that will keep them busy for 2–3 years, but even on these much-desired orders they sometimes lose money. For instance both AEG and B&W will shoulder roughly $900,000 each or over one-third of the cost of the preliminary design orders received from SKW. The government contributes $952,000 and SKW $476,000 to each of these orders. The burning question is: will the big construction orders come in time, and will they make up for earlier losses?

Maschinenfabrik Augsburg Nürnberg (MAN) has recently concluded a licensing and collaboration agreement on advanced gas-cooled reactors with Britain's General Electric Co. MAN apparently felt it had to enter the nuclear field since all other German manufacturers of complete conventional power plants were engaged in it. But there is not even a sign of a potential buyer in sight. And Siemens has developed a second reactor type (pressure boiler, natural uranium, heavy water) of 50 Mw(e) that is actually further developed than its similar pressurized-tube reactor. There is no buyer for that either.

The Utilities' Side

It is understandable, though, that the power supply companies are not rushing in to place orders as long as nuclear power costs are not competitive. Under its new nuclear aid program, the government will assume most of the operational losses of a power reactor, but the remaining 25% or more of losses are still difficult enough to justify to shareholders.

West Germany prides herself on having left development of nuclear energy to industry rather than building up strong governmental supervision. There is no AEC armed with sizeable funds to coordinate, direct, stimulate—and to a greater or lesser extent control—development of the atom. But it looks as though the price for applying the general German "free-market" policy to the nuclear industry may well be slower progress for nuclear development.

World News

Halden Reactor Critical

The Halden reactor, built by Norway's Institute for Atomic Energy and taken over for operation by a twelve-nation group of the European Nuclear Energy Agency, finally went critical June 29. World's first boiling heavy-water reactor and first boiling-water reactor in Europe, it was originally scheduled to start operation a year ago (NU, Jan. '58, 21). The 20-Mw (th) unit will be used primarily for studying boiling heavy-water systems, but will also produce 15 tons/hr of process steam in its secondary, light-water circuit. This will eventually be used in the adjacent Saugbrugsforeningen paper and pulp factory, for what is likely to be the first use of nuclear process steam. The usual reactor-physics experiments will occupy the next six months before the plant is taken to full power; official dedication will be Oct. 10. Total cost of the plant was $3.5-million, including the heavy water bought from the U. S. AEC and the first charge of natural uranium fuel from the U. K. AEA.

Largest Commercial Co^{60} Source Reaches Australia

The largest radioisotope source ever designed for commercial use—150,000 curies Cobalt-60—was to arrive in Australia last month after a secrecy-shrouded trip from the U. K. Atomic Energy Authority. British authorities classified the shipment to minimize the possibility of labor trouble on the docks. The source will be used in a sterilization plant of the Westminster Carpet Co. (at Dandenong near Melbourne) for the elimination of anthrax in raw goat hairs. The process will replace formaldehyde fumigation at an estimated saving of 25% in sterilization expenses. Cost of the source alone, which was irradiated in the Calder Hall reactors, was estimated by U. K. officials at $240,000; total cost of the facility was put at $500,000. A Co^{60} irradiator of the same strength is now under construction at UKAEA's Wantage Radiation Laboratory. Though details of both systems are secret they are known to be identical in several important respects. One big difference is handling capability: Wantage is optimized for conveyor irradiation of packages of 1 cu ft; Dandenong will process packages many times this size loaded manually.

Eklund Heads Dragon Project

Sigvard Eklund of Sweden, secretary general of the 1958 Geneva Atoms-for-Peace Conference, was elected chairman of the international board of management for Project Dragon—the British High Temperature Gas Cooled Reactor project at Winfrith Heath which, like Halden, has become a joint project of 12 nations in the European Nuclear Energy Agency (NU, July '59, 22).

Venezuela's Reactor Moving Ahead

After a brief halt last year occasioned by the revolt deposing Dictator Marcos Perez Jiménez, work on Venezuela's 3-Mw(th) pool-type research reactors is proceeding; criticality is hoped for by this fall. The new director of the project for IVIC (Instituto Venezolano de Investigaciones Cientificas) is James C. Nance, formerly with Convair's ANP group.

British Briefs

Maj. Gen. S. W. Joslin, 60, general manager of the Dounreay plant of the AEA, has been selected to become chief inspector of nuclear installations when the Nuclear Installations Bill (licensing and insurance) now going through Parliament becomes law. An amendment to the bill would give the government complete control over production of plutonium and uranium. Manufacture of fissionable materials by private industry will become illegal, except by special government permit in connection with research and development work. . . . Total cost of the **Windscale accident** in October 1957 is now put at $5.5-million, according to AEA. This includes value of materials, plant and buildings irreparably damaged, and compensation. . . . The first **reactor shell at Berkeley** has become the largest vessel in the world ever to be stress-relieved and pneumatically pressure-tested. The 80-ft high, 50-ft dia, 1,000-ton cylinder was built of 3- and 4-in-thick mild steel by John Thompson Ltd. It was heated to 1070–1200° F by internal heaters drawing 2 Mw; then—its 2,500 ft of welds having been X-rayed—it was tested at 211 psig (design and working pressures are 137 and 125 psig respectively).

Plutonium Meeting in France Next Year

The French Society for Metallurgy is organizing an international symposium on the metallurgy of plutonium, to be held April 19–22, 1960, at Grenoble.

Expansion in South Africa

A new, long-range atomic research program recommended by the Atomic Energy Board of the Union of South Africa will get under way in a few months. It will focus on cheapening and simplifying uranium production, and learning to handle and use nuclear metals like zirconium and beryllium of which South Africa also has large reserves. Biggest single research project ever launched in South Africa, it will be financed by $1.4-million from industry, especially the mining industry, and $840,000 from the government. The program will probably include a research reactor, South Africa's first.

Radiation Protection Agreement in Europe

The 17 OEEC nations agreed on common measures to safeguard populations from radiation. The OEEC Council adopted a decision requiring member countries to ensure adequate health protection for all persons who might be exposed, whether occupationally or otherwise. All countries must report to the European Nuclear Energy Agency by Nov. 15 on measures taken; ENEA will make a comprehensive survey by year's end.

Japanese Design BWR Tanker

Another group in Japan has produced a blueprint for a nuclear-propelled merchant ship—the Nitto Shipping Co. and four associates* who have planned a 60,000-ton deadweight, 28,000-hp tanker driven by a boiling-water reactor. Cost of the nuclear tanker is estimated $14.2-million—including a $4-million, 80-Mw(th) direct-cycle boiling reactor—as against $9.7-million to build a conventional ship. The reactor with its container would weigh 1,530 tons. Its 10.6-ton charge of 2.5%-enriched uranium dioxide would give it a cruising speed of 17.5 knots. It would be installed aft, alongside a take-home 2,000-hp auxiliary boiler giving 8-knot speed. Burnup is placed at 10,000 Mwd/ton, core life at four years. Nitto expects to import the reactor, which it chose over a pressurized water on the ground that it would be cheaper, not requiring heat exchangers.

* Ishikawajima Heavy Industries, Tokyo Shibaura Electrical (Toshiba), Harima Shipyard, and Nippon Atomic Industry Group (NAIG), all affiliates of the Mitsui group.

DRD Considering Decentralization of Reactor Program

AEC's Division of Reactor Development is considering decentralization of the power reactor program by assigning technical coordination of specific concepts to the operations offices.

If the idea is cleared by DRD's superiors and put into effect beginning this fiscal year, as hoped, the division would become increasingly free to devote its efforts to evaluation and planning.

Under pressure from budget-related manpower ceilings for some time, Division Director Frank Pittman has reportedly felt that his staff was ill-prepared to do the planning he would like to see emphasized at division headquarters. A prime example of this new emphasis, of course, is the effort already underway to determine where and how the reactor program should be going over the next ten years (NU, July '59, 17).

Tentative steps toward decentralization were begun soon after Pittman took over as acting director at DRD last summer. One of his early acts was to establish a system of task forces—staffed primarily by people in the field—to evaluate questionable programs. Out of their work came ultimate decisions to: **1.** drop the sodium-deuterium work centered in the Chugach, Alaska project; **2.** drop the Liquid Metal Fueled Reactor Experiment and cut back drastically on all fluid-fuel concepts; and **3.** design a carbide core for the sodium reactor at Hallam.

After Pittman was named division director in October (NU, Nov. '58, 22) he asked Oak Ridge and Argonne to handle one-shot jobs—ORNL to evaluate and prepare conceptual design of a small power reactor and ANL to do the same for process-heat and boiling-water reactors. Oak Ridge Operations was assigned administration of the gas-cooled reactor initially designed by ACF-Kaiser and to be built at Oak Ridge (NU, July '59, 18). OROO may also be asked to assume coordination of all gas-cooled work under the reactor program, including the Philadelphia project, if the decentralization plan jells. There is some concern, however, that OROO's relatively inaccessible location might demand assignment of gas coordination to an East or West Coast operations office.

Three operations offices already have tentative assignments: pressurized water to New York; heavy water to Savannah; and boiling water to Chicago. These offices are thinking about staff buildups they must make to qualify for concept coordination but there remains some question on whether there might be shrinkage at Germantown.

U. S. Acts to Bolster IAEA Fuel and Research Program

An agreement for cooperation between the U. S. and the International Atomic Energy Agency—aimed primarily at permitting AEC to sell enriched uranium to the Agency—went into effect last month even as AEC Commissioner Harold Vance was predicting that not more than 500 kg of the 5,070 kg committed for delivery to IAEA would ever be shipped under the supply agreement.

Speaking for himself and not for the Eisenhower Administration, Vance told the Joint Committee on Atomic Energy in blunt language that he did not believe "it is one of the major functions of the IAEA to act as a broker between countries dealing with enriched U."

When JCAE Chairman Clinton Anderson (D-N. M.) pointed out that President Eisenhower had argued since IAEA's beginnings that nuclear fuel supply and control "was a major IAEA function," Vance replied: "I'm giving you my opinion—not the President's."

Meanwhile, NUCLEONICS learned that AEC was working quietly to shore up the Agency's stock—both in fuel supply and in increased financial support for Agency-sponsored research.

On **fuel,** the Commission's staff was trying to find a solution to the very problem which Vance pointed to as effectively blocking IAEA's aspirations as a fuels broker—how to sell uranium to the Agency at terms which would permit resale at a price no higher than a member country would pay in buying directly from AEC.

On **research,** AEC signed its first contract with IAEA under the program laid out last fall in Vienna by Chairman John McCone (NU, Oct. '58, 26)—assignment of AEC-funded research contracts to IAEA for reassignment to member countries.

A $20,000 contract was awarded to the Agency shortly before the end of June for research to be done at Harwell (U. K.) and Saclay (France)—development of methods for the enriching of calcium in the calcium-46 isotope. The material would then be irradiated to produce calcium-47, a short-lived isotope used in biology and medicine.

AEC officials said that no specific amount had been budgeted for U. S. supported, Agency-sponsored research but that substantial funds were available for additional contracts. Projects will be selected from both AEC and IAEA programs.

In the meantime, IAEA's board of governors has decided to recommend an expanded program of fellowships, technical assistance, seminars and exchange in 1960 to the third General Conference of the Agency opening in Vienna Sept. 22. The board will propose a '60 budget of $8,233,000, up $708,000 from '59, and a staff increase from 221 to 239.

Con Ed Progresses on Indian Point Plant

Latest air view of Con Edison's Indian Point, N. Y., reactor shows it beginning to take on its final shape. Precast concrete ribbing has been placed for the concrete reactor dome which will surround the inner steel containment sphere (visible through ribs). To left is steelwork for two oil-fired super-heaters, then concrete pedestal foundation for turbine. The plant is to begin operating in April 1961.

News in Brief

House Group Again Hits AEC's Isotope Program . . .

As it did last year, the powerful House Appropriations Committee has attacked AEC's plans to support industrial research and development on radioisotopes under the Isotope Development Program (IDP). In closed-door hearings last month, Committee members took party-line positions—Democrats against, Republicans for—on an AEC request for $6.2-million to fund contracts with industry during fiscal '60 (beginning July 1). Last year, the Committee cut AEC's IDP request by 60%—reducing it to $2-million—though the total eventually available was $4.2 million (NU, Sept. '58, 154, Oct. '58, 21). Committee Chairman Clarence Cannon (D-Mo.) led the attack on the '60 budget, arguing that industry should be left to invest its funds in isotope development.

. . . As AEC Commits More of '59 Funds

More than $500,000 in additional Isotope Development Program commitments were announced last month by AEC's Isotope Development Office (NU, July '59, 24). Grants for training equipment totalling $272,712 went to 20 colleges and universities, bringing the total to $604,416 in grants to 33 institutions. Another $275,000-plus went for research-development contracts:

1. Nuclear Science and Engineering. A one-year contract for $122,000 to development an isotopic method for assaying the body's growth hormone; contract expires in March.

2. Picker X-Ray Corp. A 10-month contract for $41,500 to develop an X-ray generator for remote locations using focused beta rays from an isotopic source; contract expires in January.

3. Evans Research and Development Corp. A one-year contract for $25,500 to develop an industrial particle-size analyzer using a beta-particle back-scattering technique; contract expires in April.

4. Aerojet-General Nucleonics. A 6-month contract for $63,200 to develop a radioactive, independent transducer-receiver system for measuring temperature, pressure and strain; expires in December.

5. Texas Engineering Experiment Station. A one-year contract for $26,400 to study the feasibility of using computer-coupled activation analysis techniques in petroleum and other industrial applications; expires in April.

Mexico, Virginia Join Texas in Waste Protests

The Texans fighting disposal of radioactive wastes in the Gulf of Mexico (NU, Feb. '59, 29) have gotten a little moral and practical support, respectively, from vocal citizens of Virginia and the Government of Mexico. Virginians raised a howl when a panel of the National Academy of Sciences/National Research Council cleared 28 offshore areas for dumping of low-level wastes, including an area less than 50 mi from the Virginia coast. Mexico registered a formal protest against the disposal of wastes off both the Gulf and Pacific coasts of the U. S., and asked AEC to withhold a license from Industrial Waste Disposal Co. of Houston. Combined with increasingly vigorous objections from various Texas sports and fishing interests, the Mexican protest led to a full-fledged review of the firm's licensing case by the AEC after AEC Examiner Samuel Jensch had recommended the issuance of a license. Oral argument before the Commission on Jensch's decision will be held Oct. 13.

Notes on State Regulation

The **State of California** has adopted legislation creating the post of coordinator of nuclear development and radiation protection and establishing an advisory council on nucleonics; the law also requires registration and licensing of all engaged in nucleonics or possessing radiation sources. . . . In **Minnesota**, the Senate blocked Gov. Orval Freeman's effort to establish a nuclear advisory board by refusing to act on legislation passed by the House; the board would have had the types of function usually handled by a coordinator, including cooperation with AEC and advice to the governor and legislature on state needs. . . . In **New York**, Gov. Nelson Rockefeller named a 15-man general advisory committee to the Atomic Development Office (NU, Apr. '59, 178).

HPS Certification Plans Still Hanging Fire

The Health Physics Society has decided to postpone—until this fall at the earliest—implementation of its program to certify health physicists (NU, May '59, 35). When a program is adopted, it is expected to contain these major elements: **1.** a certification board outside HPS will run it; **2.** to qualify, all applicants will have to meet certain requirements, including five years' experience and submission of two hazards evaluations or their published equivalent; and **3.** all applicants after a given date (probably July 1, 1960) will have to take written and/or oral examination.

News From GE, General Atomic, High Voltage

General Electric's Atomic Products div. under Lyman R. Fink has moved its headquarters to Palo Alto, Calif., "in order to be nearer" three of the division's major components—Atomic Power Equipment dept., San Jose; Hanford Atomic Products operation, Richland, Wash.; and the National Reactor Testing Station, where GE has many of its nuclear aircraft activities. . . . **General Atomic** has dedicated its $10-million John Jay Hopkins Laboratory for Pure and Applied Science—with the help of Niels Bohr and 2,000 scientists and government officials from around the world. The lab's Triga research reactor was flashed from 1 watt to a record peak of 1.5-million kw(th), the flash lasting 0.0015 sec; an impulse from the flash served to unveil the dedication plaque. . . . **High Voltage Engineering Corp.** has sold a 3-Mev Van de Graaff accelerator to the Westphalian Technical Institute, Aachen, Germany.

Argonne Breaks Ground for Synchrotron

AEC broke ground at Argonne National Laboratory June 27 for its 12.5-Bev, $29-million Zero Gradient Proton Synchrotron (ZGS). The torus-shaped accelerator in its 200-ft dia housing will be completed in early 1962.

Notes on D_2O to India, Nuclear Ships, Merger

AEC signed a contract with the **Indian government** last month to lease 15 tons of heavy water for the initial inventory of India's Zero Energy Research Reactor, Trombay. . . . Sen. John Marshall Butler (D-Md.) has introduced a Senate bill (S. 2336) to provide federal aid—beyond existing subsidies—for construction of **nuclear merchant ships**; no action is expected this session of Congress . . . The **Cross Co.**, Detroit automation firm, has acquired **Stephen F. Malaker Associates**, radiation consultants; the Cross-Malaker Laboratories, Inc., has been established at Mountainside, N. J.

Winfrith Work Underway

Britain's second major reactor development center at Winfrith Heath, Dorset, is coming to life. An advanced team of engineers and physicists is already at work; the Harwell reactor team will start transferring to Winfrith in October.

Since work began in September 1957 at Winfrith, $15-million has been spent; when fully developed by 1962–3 capital cost will exceed $75-million and the facility will employ 2,500. It will provide for six reactor experiments up to 10-Mw(th) each plus a complex of zero-energy and exponential facilities. A second Nero-type research reactor will be one of the first facilities on the site.

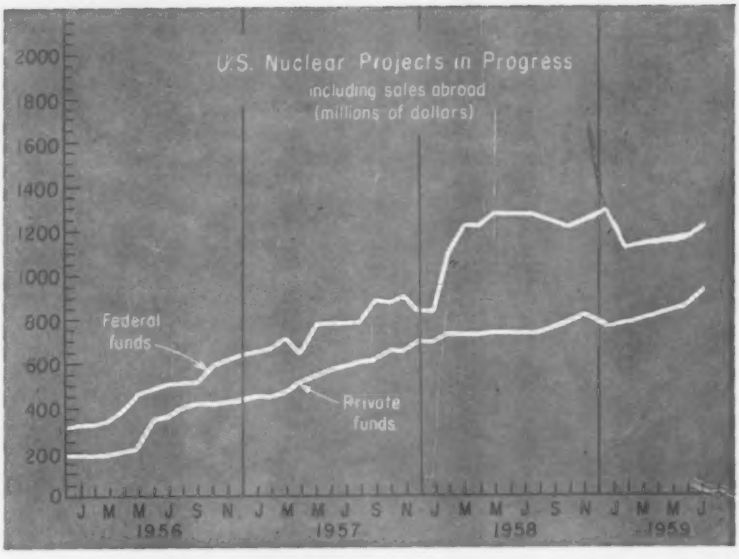
First development project at Winfrith is the High Temperature Gas-Cooled power reactor, which is proceeding in three stages: a zero-energy version called Zenith, a 10-Mw version called Dragon, and finally HTGC itself. Testing operations are already well advanced on Zenith and it is expected to start up in October. The $1-million unit will permit study of the temperature dependence of nuclear parameters at 800° C (1470° F), same temperature as that at which Dragon will operate. Like Dragon, Zenith will have a reactor vessel 10 ft dia, 11 ft long; it is to be nitrogen-cooled. Fuel pellets, contained in graphite sleeves, are a mixture of uranium and thorium oxides. Dragon will be built and operated jointly with OEEC's European Nuclear Energy Agency, and Zenith is also to be loaned to the ENEA Dragon team of 60 engineers and scientists.

Go-Ahead on Huge Linac?

A 10–15-Bev electron accelerator for construction at Stanford Univ. was expected to be authorized by Congress before it adjourns.

At JCAE hearings on the linac last month, AEC was criticized sharply for delaying its $105-million request and failing to give JCAE enough time for study. However, the project was expected to be cleared.

AEC officials said the machine, designed for upsizing to 45-Bev, would: 1. provide an incomparable source of anti-nucleons and strange particles; 2. aid studies of electromagnetic-particle production; 3. aid studies of nucleon structure; 4. significantly increase knowledge on laws of electromagnetism; and 5. open new scientific fields.



NUCLEONICS Statistics of the Month

	Latest month	Month Ago	Year ago
Nuclear Contracts *—			
Contracts awarbeb for feberal projects ($10³)	11,276	129,265	7,418
Proposeb construction, privately-owneb ($10³)	0	0	0
Contracts awarbeb, private work ($10³)	30,000	0	0
Backlog of private projects ($10⁶)	285	285	249
Isotope Use †—			
Applications for isotope use	700	651	512
Cumulative total of isotope users	5,017	4,867	3,790
ORNL shipments (curies)	25,304	63,900	n.a.
Pudlic anb private export shipments	85	276	286
Employment †—			
AEC employment	6,649	6,676	6,815
Construction anb besign contractors' employment	9,756	7,490	10,328
Total operating contractors employment	104,116	104,434	113,686
Probuction workers	51,555	51,761	51,400
Research anb bevelopment employees	47,390	47,254	45,087
Miscellaneous workers	5,171	5,419	6,871

U. S.-built Reactors ‡—

	Operating	Builbing	Contracteb
Power, bomestic	1	7	7
Power, for export	0	3	2
Power experiments anb pilot plants	6	5	0
Military anb naval	10	44	5
Research anb test, bomestic	58	21	47
Research anb test, for export	14	14	9
Total	89	94	70
Foreign-built Reactors ‡—			
Power, bomestic	10	28	17
Power, for export	0	2	1
Research anb test, bomestic	34	11	11
Research anb test, for export	8	6	0
Total	52	47	29

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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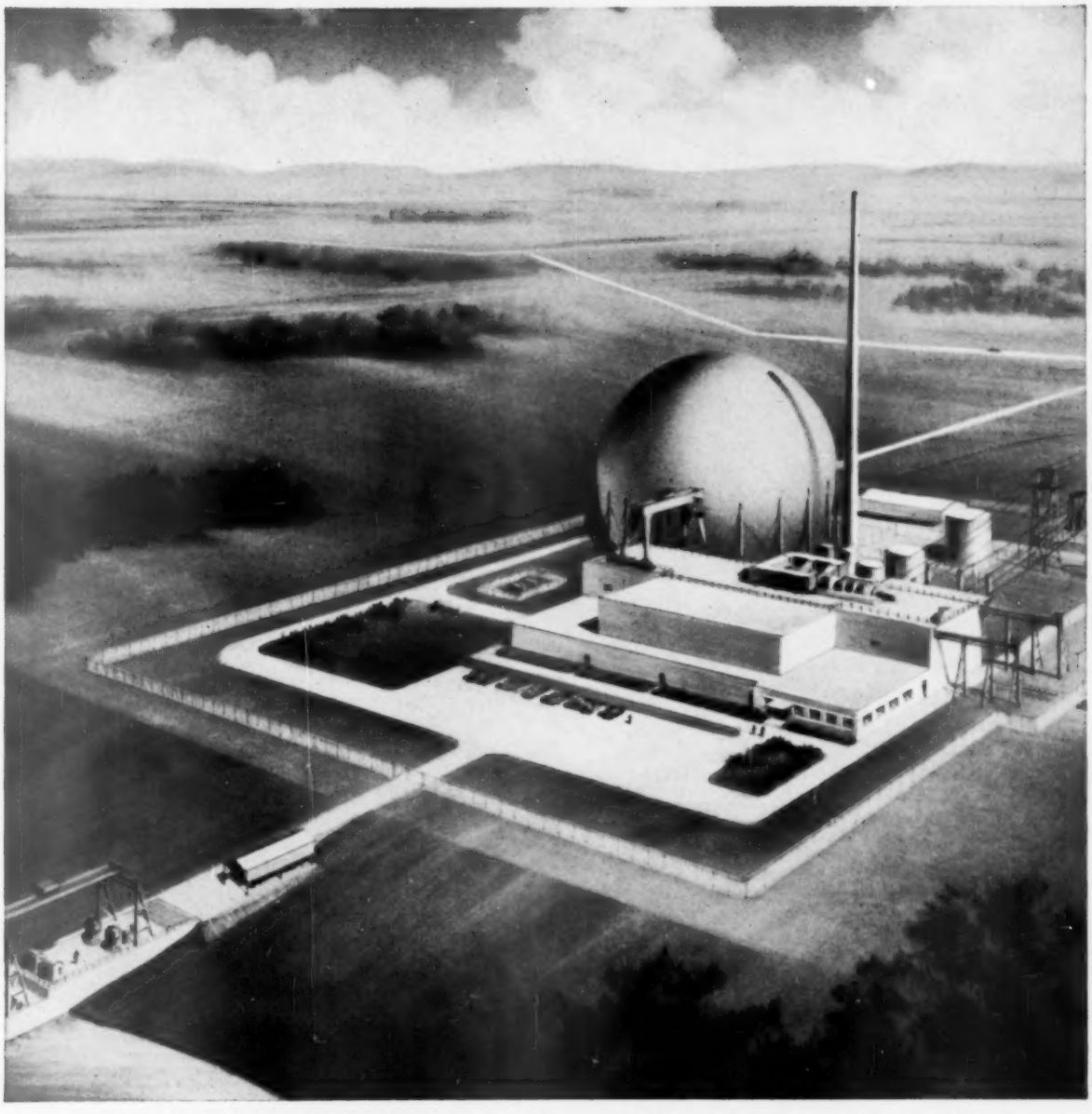

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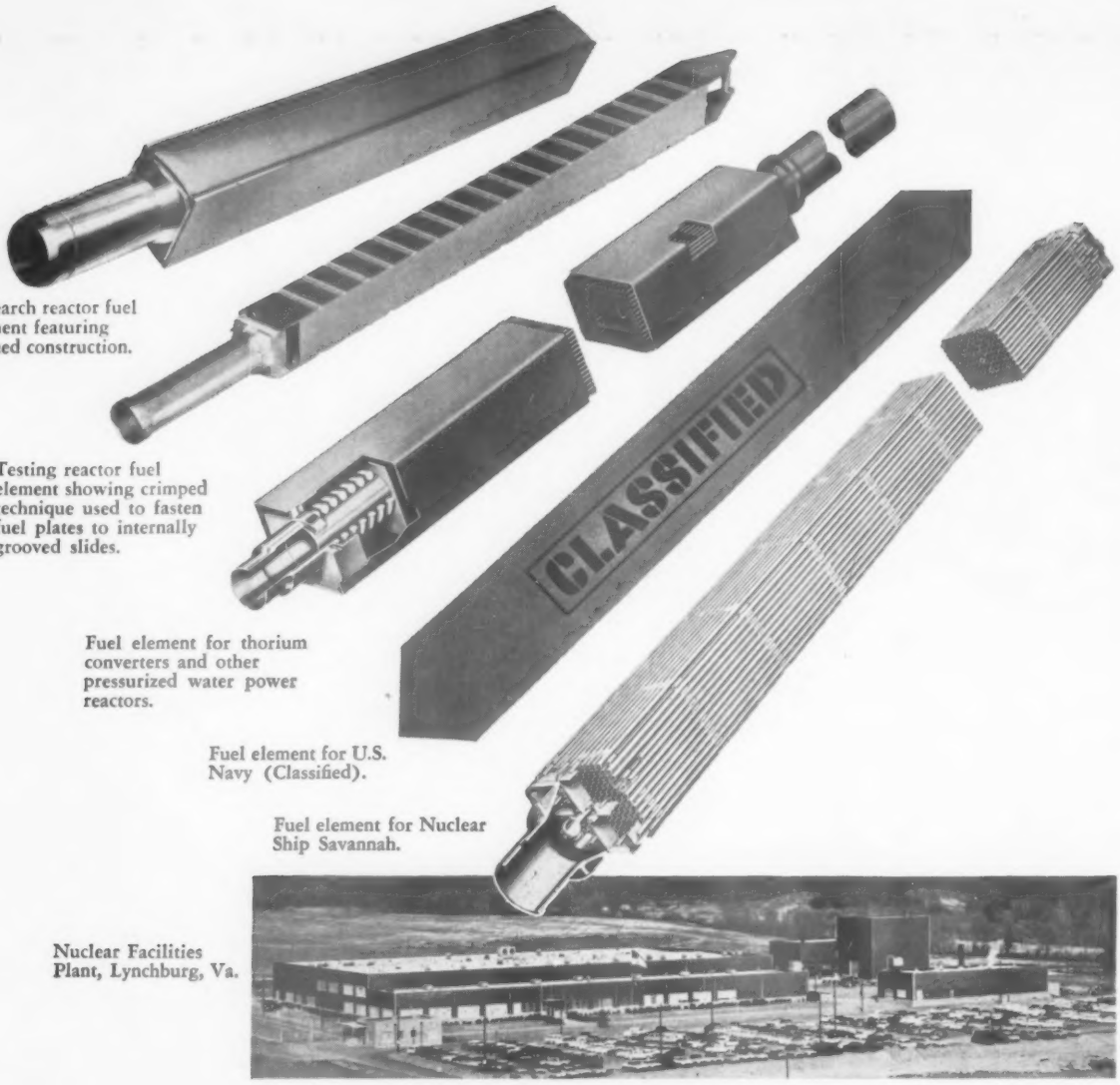

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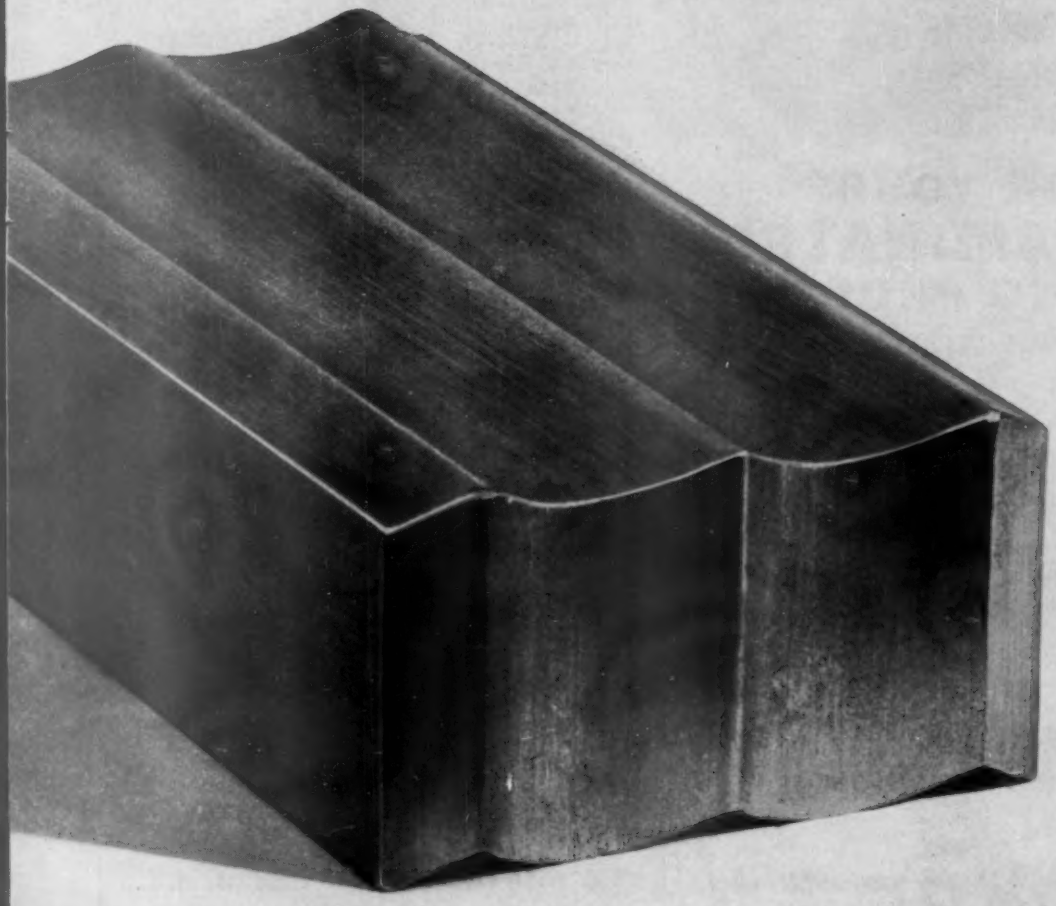

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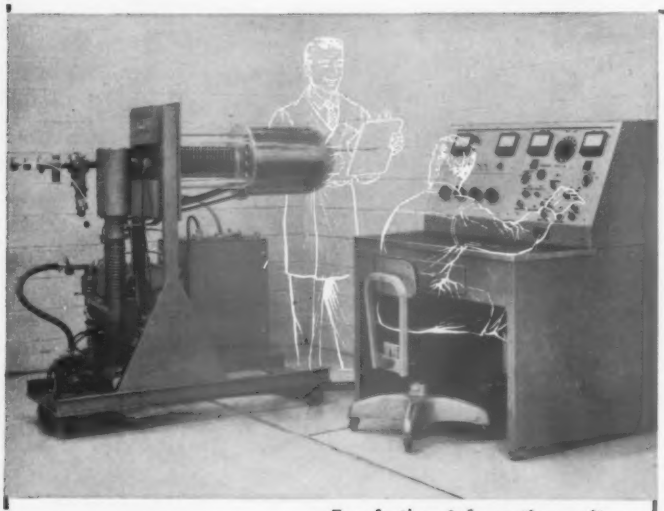

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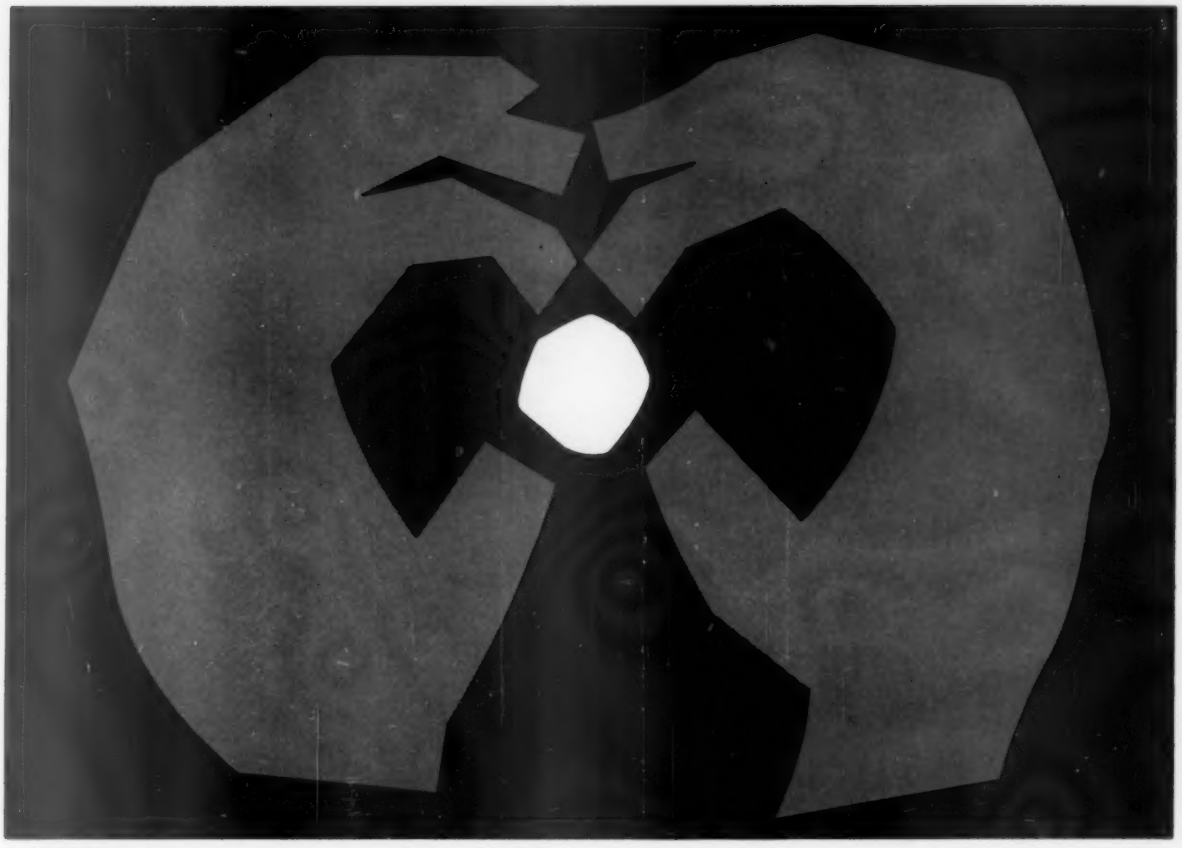

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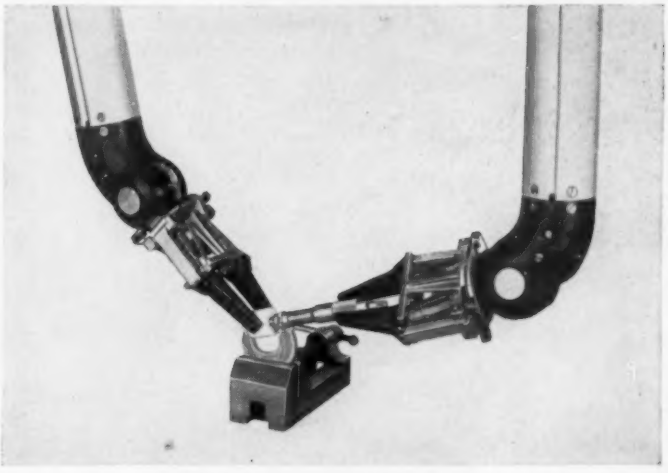
Simplicity of operation is only one of several reasons research and production organizations all over the world specify CRL Manipulators. The system is versatile. Accessories such as special-purpose tongs, load hooks, motion locks, and protective booting allow adaption to a great variety of purposes. A continuous program of improvement . . . uncompromising workmanship . . . and standardized, interchangeable parts provide more reasons why you should consider CRL Manipulators for handling hazardous materials.

Central Research Laboratories will be glad to advise you on the handling of radioactive materials, explosives, hazardous chemicals, biological materials—in the layout of hot cells—in other research areas, too. For complete information, write CRL today.



Central Research Manipulators from basic Argonne National Laboratory design

Central Research
laboratories, inc.
Red Wing, Minnesota, Dept. 101

KEITHLEY MODEL 150 MICRO VOLT-AMMETER

MEASURES DOWN TO 0.03 μv AND 2 x 10⁻¹² AMPERE

The Keithley 150 sets new standards in sensitivity, stability and noise figure for dc microvoltmeters. It also serves as an amplifier, null detector, micro-microammeter, and (with an external voltage supply) meg-megohmmeter. Functions and measurement spans include:

DC Voltmeter, 1 microvolt to 1 volt full scale
Ammeter, 10^{-10} to 10^{-3} ampere full scale
DC Amplifier, gains of 10 to 10,000,000
Null Detector, with 0.5 to 2 second period.

OTHER FEATURES of the 150 include zero suppression of up to 100 times full scale; optional floating or grounded input; high input resistance; zero stability as a voltmeter within ±0.1 microvolt per day, and within $\pm 2 \times 10^{-11}$ ampere per day as an ammeter; short term noise within 0.03 microvolt peak to peak (0.006 microvolt RMS). The 150 is rugged, relatively insensitive to vibration, 60-cycle fields, or thermal EMF's. It is available in either rack or cabinet packaging.

USES of the 150 encompass nearly every branch of research and engineering. Examples include measuring the outputs from strain gages, thermopiles, thermocouples, bolometers, phototubes, ionization chambers, scintillation counters, and barrier layer cells. Other applications are found in cell studies, electrochemical potentials, corrosion work, molecular-weight analysis, Hall effect studies.

DETAILED DATA about the 150 Micro Voltammeter are now available in Keithley Engineering Notes, Vol. 7 No 1. A request will bring your copy promptly.

BRIEF SPECIFICATIONS

dc voltage: 13 ranges in 1X and 3X steps from ±1 microvolt to ±1 volt full scale.

current: 17 ranges in 1X and 3X steps from $\pm 10^{-10}$ to $\pm 10^{-3}$ ampere full scale.

zero stability: within 0.1 microvolt per day, or 2×10^{-11} ampere per day.

noise: less than 0.006 microvolt RMS as a voltmeter; less than 2×10^{-12} ampere as an ammeter.

accuracy: voltage, ±2% of full scale on all ranges; current, ±3% on all ranges.

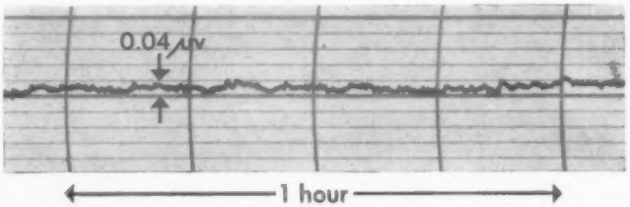
zero suppression: up to 100 times full scale.

response speed: 0.5 to 2 seconds.

gain: 10,000,000 maximum.

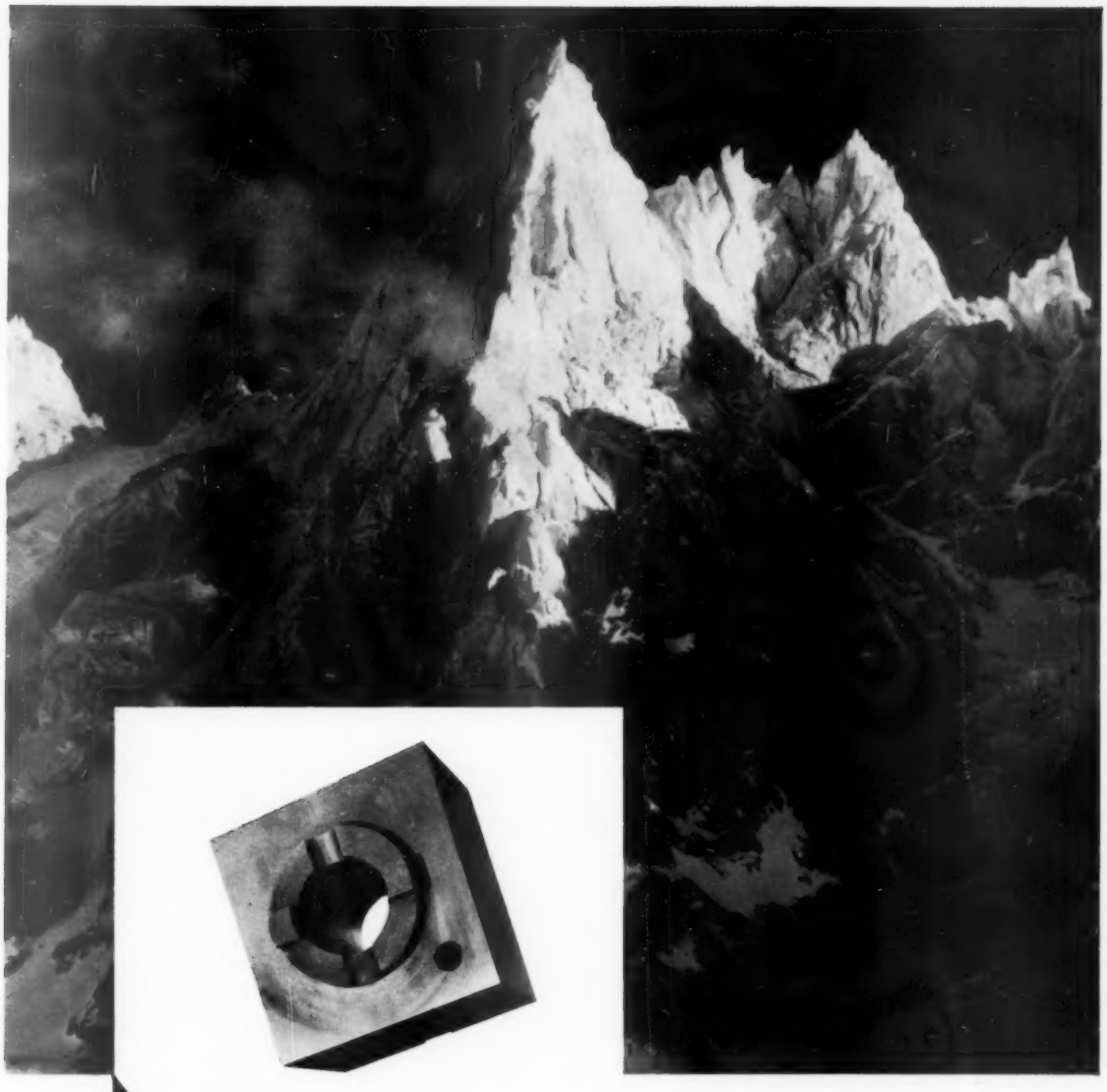
output: ±10 v and 5 ma for full scale deflections.

price: $675.00



Long-term drift of the Model 150 is shown in the above recording. A 1000-ohm resistance was connected across the input. Note the very low peak to peak noise, even at this slow paper speed.

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE CLEVELAND 6, OHIO



Graphite

Machined or unmachined

Moderator or reflector

Density 1,60 to 1,75 g/cm³
Cross-section 3,8 to 4,5 mb

PECHINEY Division Applications Atomiques
23 RUE BALZAC PARIS 8e

Navy goes fission again

On this vertical boring mill at U. S. Steel's Homestead Plant, you see a forged steel flange that will serve aboard one of the Navy's new guided missile frigates. These are an entirely new class of naval vessel—their primary mission is the destruction of air targets and they are nuclear-powered.

The flange will be welded to other forged steel parts to form a sealed nuclear reactor vessel. Only a forging of the very best quality is suitable for this critical service. To obtain this quality, vacuum-cast electric furnace steel was used. The flange was carefully forged from a Ni-Cr-Mo alloy ingot about 72" in diameter and was heat treated to meet rigid specification requirements. Mechanical tests as well as magnetic particle and sonic inspection methods were utilized to assure a quality product. As shipped, the flange weighed over 21½ tons.

Many nuclear forgings like this one are made by U. S. Steel because here, the complete production is supervised and controlled by a team of forging experts. They melt the steel, pour the ingot, forge, heat treat and machine it. The very same team of USS Forging experts who made this flange will fill your order. We welcome your inquiries or requests for our free 8-page booklet about USS Nuclear Forgings. Write to United States Steel, 525 William Penn Place, Room 6032, Pittsburgh 30, Pa.

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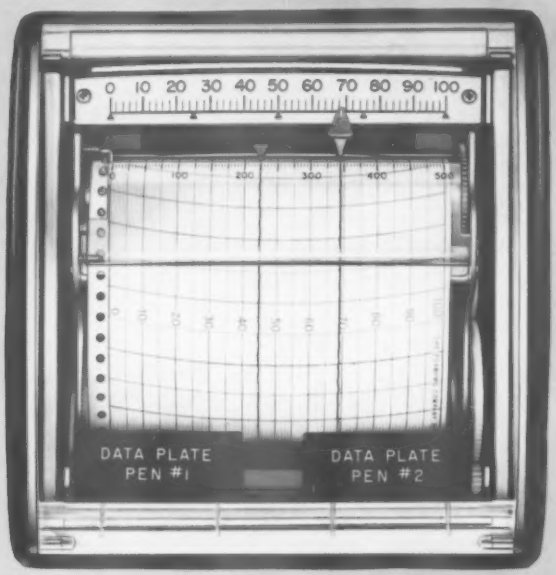
United States Steel Export Company

United States Steel

USS

another unit in Foxboro's **exclusive** 100% solid-state electronic Consotrol* system

Simplest most reliable electronic recorder yet!



Foxboro M/64 Electronic Consotrol Recorder
(shown ½ actual size)

no amplifiers...no electrical adjustments

The precision and speed of electronics...*plus* the simplicity and reliability previously associated only with pneumatics. That's the new Foxboro M/64 electronic Consotrol recorder.

The M/64 uses a powerful magnetic torque motor to operate pens directly from a high-level 10-50 ma d-c signal. There's no amplification necessary—no slidewire or rebalancing unit. 4-inch vertical strip chart gives full-scale readability of records. One and two-pen models available for semi-hazardous or non-hazardous service.

The M/64 slides out of its housing like a drawer, so all servicing may be done from the front of the panel. Yet there is no interruption to recorder operation! What's more, zero, span, and linearity are all simple mechanical adjustments, so familiar to pneumatic instrument users.

Write today for Bulletin 21-10. It describes the new M/64 Recorder in detail, as well as the many other advanced instruments in Foxboro's complete 100% solid-state electronic control system. **The Foxboro Company, 628 Neponset Ave., Foxboro, Mass.**

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ACCESSORIES	. . . films, tanks, darkroom sundries, illuminators, *everything*

Picker x-ray

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Griscom-Russell has for over 90 years offered an extremely wide line of bare and finned tube heat transfer equipment for all industries — we can give you exactly what you need.

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GR 397

Swagelok® engineers believe that NO fitting is too good if it keeps your plant in operation

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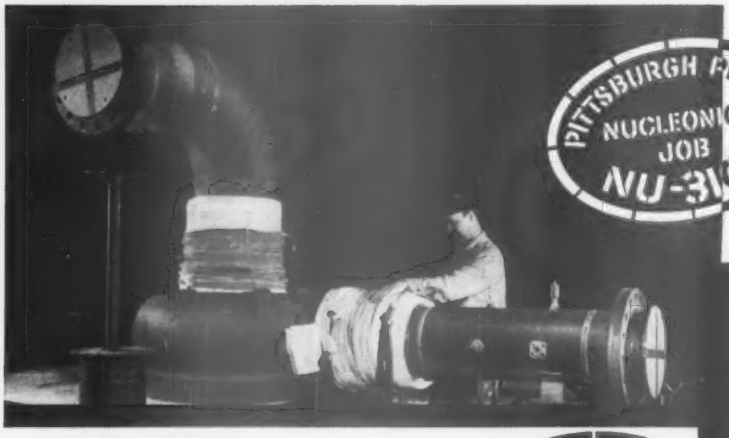
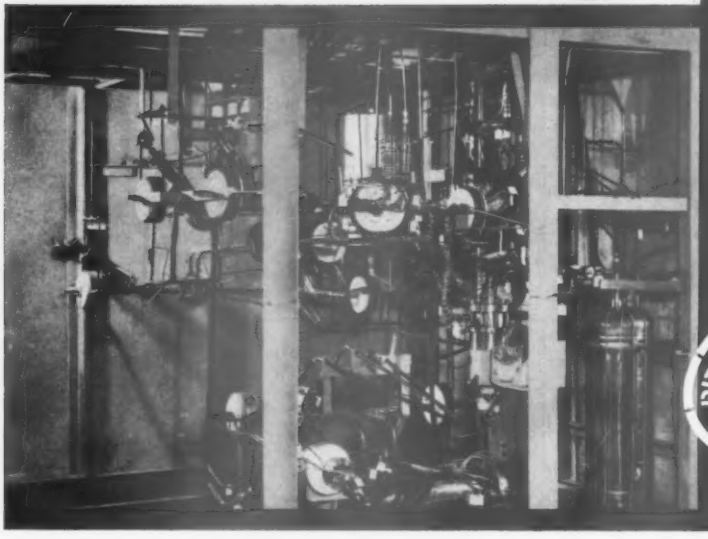


VOLUTE ASSEMBLY

BULKHEAD PENETRATOR



STAINLESS STEEL LOOP

Fabricated by Pittsburgh Piping for Nucleonics

These jobs demonstrate the variety of nucleonic piping work done in our shops. The volute assembly, shown in intermediate stage of manufacture, is fabricated of 14" and 16" Schedule 160 piping materials. The bulkhead penetrator, one of a group, is notable for an unusual method of welding dissimilar metals. The complex test loop requires skillful welding of stainless steel piping materials, and precise assembly of hundreds of components. We are equipped and staffed to do similar jobs for you. Telephone, or write and our representative will call. Or, we will be glad to have you visit our plant.

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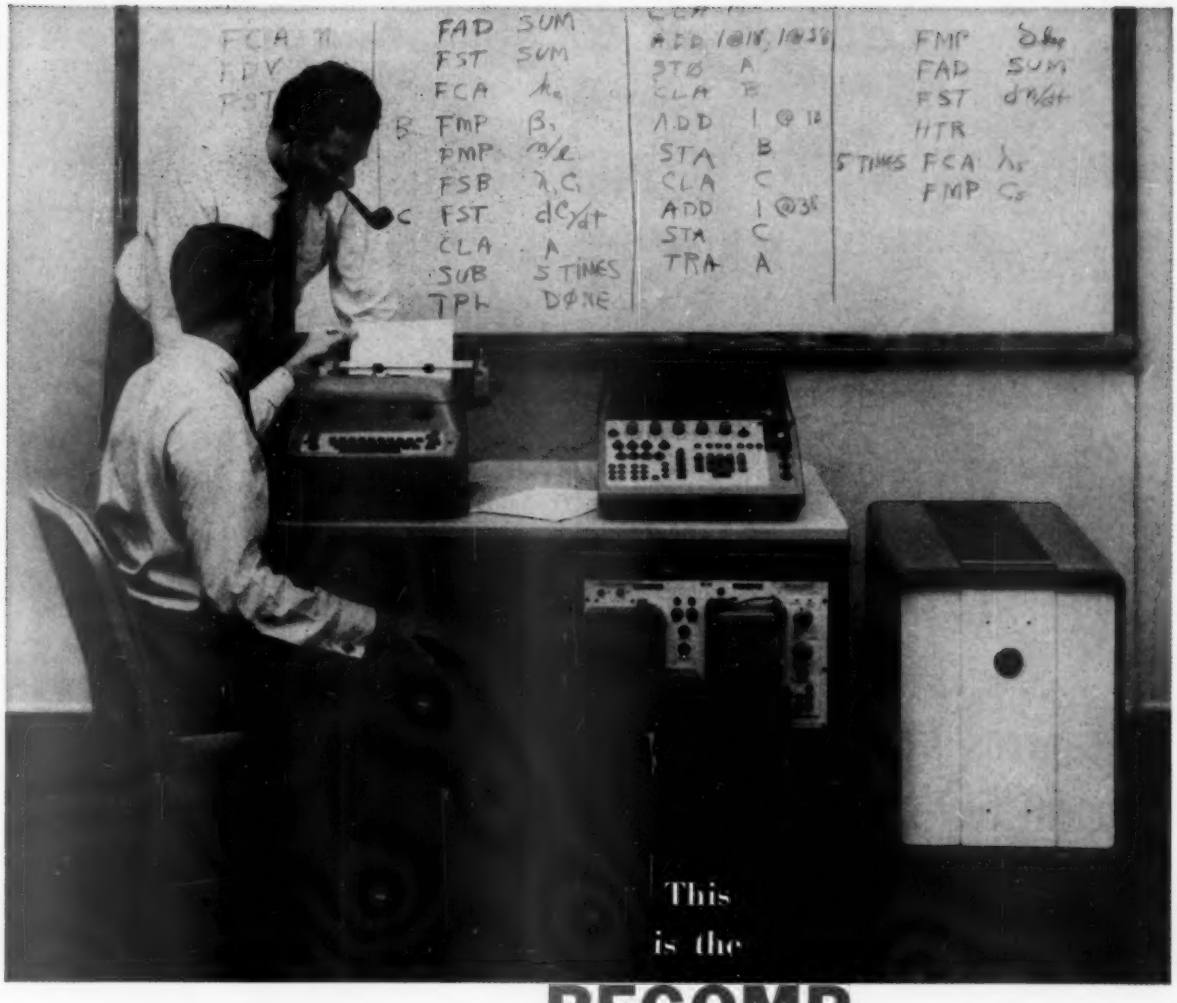

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digital computer

It has a storage capacity of 8,000 instructions ... and it's low-priced

No problem is too complex to tackle with Recomp—and you can afford to put it wherever it's needed to break up computer-time bottlenecks. It's easy to use, too; engineers quickly learn to program their own problems. *Other Recomp features:* a command structure of 49 arithmetical and logical commands—including 9 built-in floating point commands ... standardized teletype tape configuration ... all-transistorized ... 400-character-a-second input ... electronic console that puts all basic controls within fingertip reach ... simplified coding. Recomp gives you far more capacity, versatility, and trouble-free service for your money. It's available for sale or lease. *There's no extra equipment to buy ... no cost of installation.* Please write for complete literature. Industrial Products Division, Autonetics, Dept. 28, 3584 Wilshire Boulevard, Los Angeles 5, California.

This engineer learned to program Recomp in two days

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for sources from millicuries to spent fuel elements...

lead shield from a ¼ inch to over 3 feet thick.....

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Contact Ameray today about their complete line of nuclear shielding products. Your shielding requirement will be **safety engineered** to meet exact specifications.

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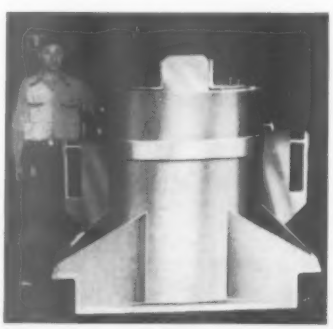
ISOTOPE CONTAINERS



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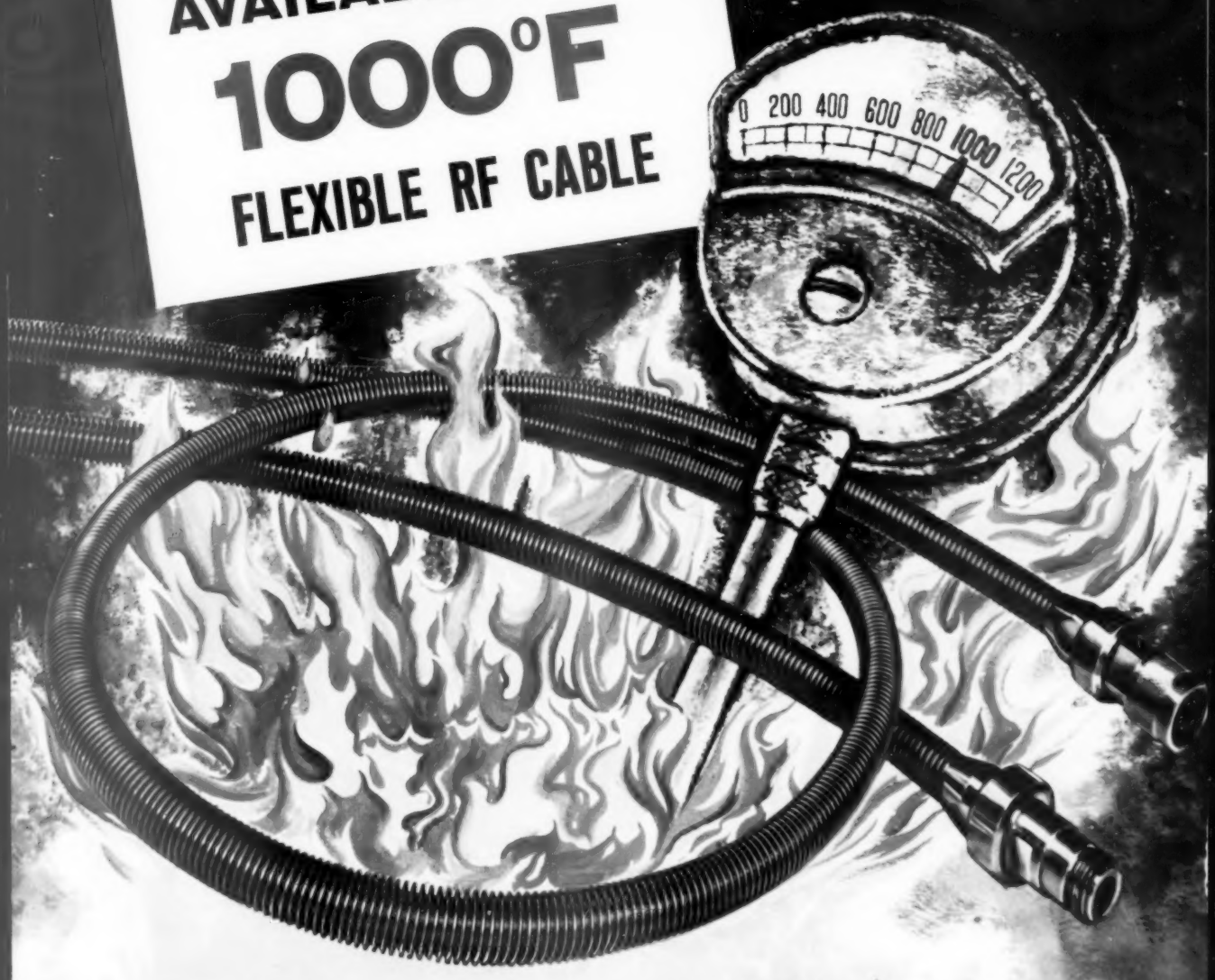
1000°F
FLEXIBLE RF CABLE



A flexible RF cable that will operate continuously at 1000°F is ready *now* for missile, aircraft, spacecraft and other ultra-high temperature applications. Capable of short time excursions to higher temperatures, the cable is a sealed RF transmission system complete with connectors. It is available in standard lengths up to 200 feet. (Patent Pending)

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Resistant to Nuclear Radiation
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Capacitance: 30.0 μμf/ft.
Velocity of Propagation: 69.0%
Voltage Breakdown: 3500 Volts RMS
Maximum Operating Voltage: 1000 VRMS
Weight: Cable, 17.5 pounds per 100 feet
Connectors, 2½ ounces each

AMPHENOL

CABLE & WIRE DIVISION

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AMPHENOL CABLE & WIRE DIVISION
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- ☐ Send additional engineering information.
- ☐ Have AMPHENOL Representative contact me.

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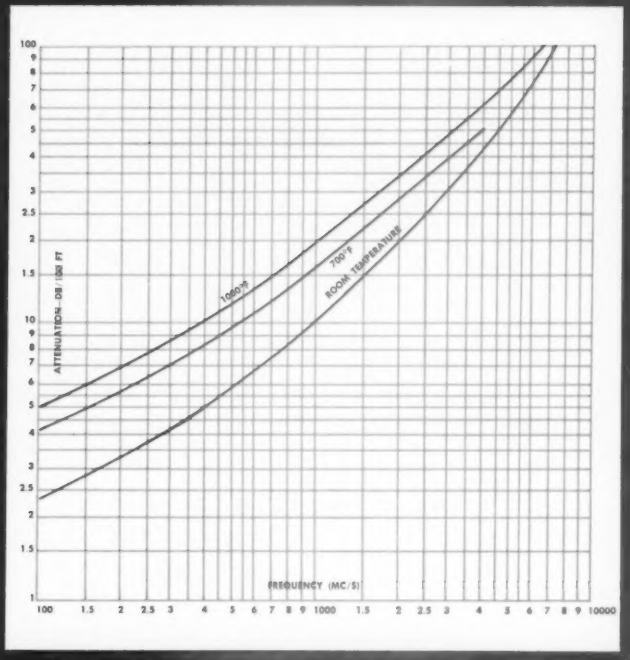
1000°F FLEXIBLE RF CABLE

PHYSICAL CHARACTERISTICS

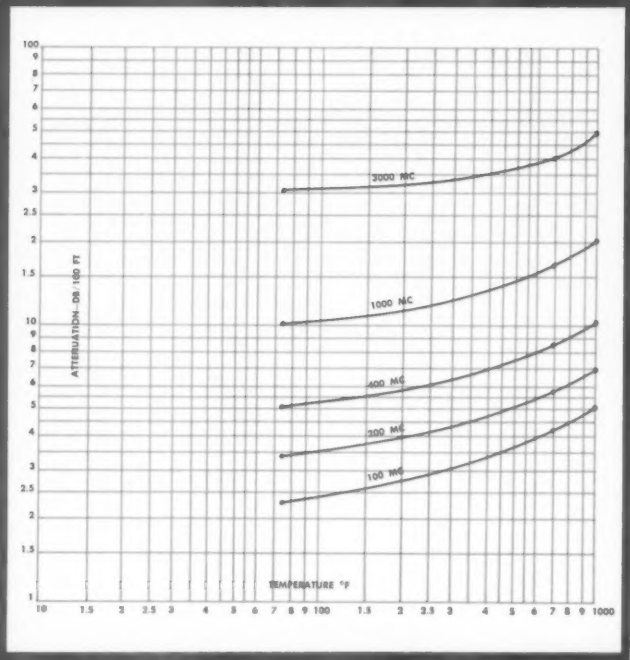
DESCRIPTION	CONSTRUCTION DETAILS
Inner Conductor	Stranded coated oxygen-free, high-conductivity copper wire.
Cable Core	Modified semi-solid silica.
Outer Conductor	Single braid, AWG size 32 coated oxygen-free, high-conductivity copper wire.
Jacket	Flexible special metal alloy. Nominal overall diameter: .525".

FLEXING CHARACTERISTICS

Cable can be bent on a 10X mandrel (bend diameter=10X diameter of cable). Cable dielectric shows no deterioration after 30,000 cycles of bending over 10X mandrel in accordance with specification MIL-C-915.



ATTENUATION VS. FREQUENCY AT ROOM TEMPERATURE, 700°F and 1000°F



ATTENUATION VS. TEMPERATURE AT VARIOUS FREQUENCIES

(See Other Side)

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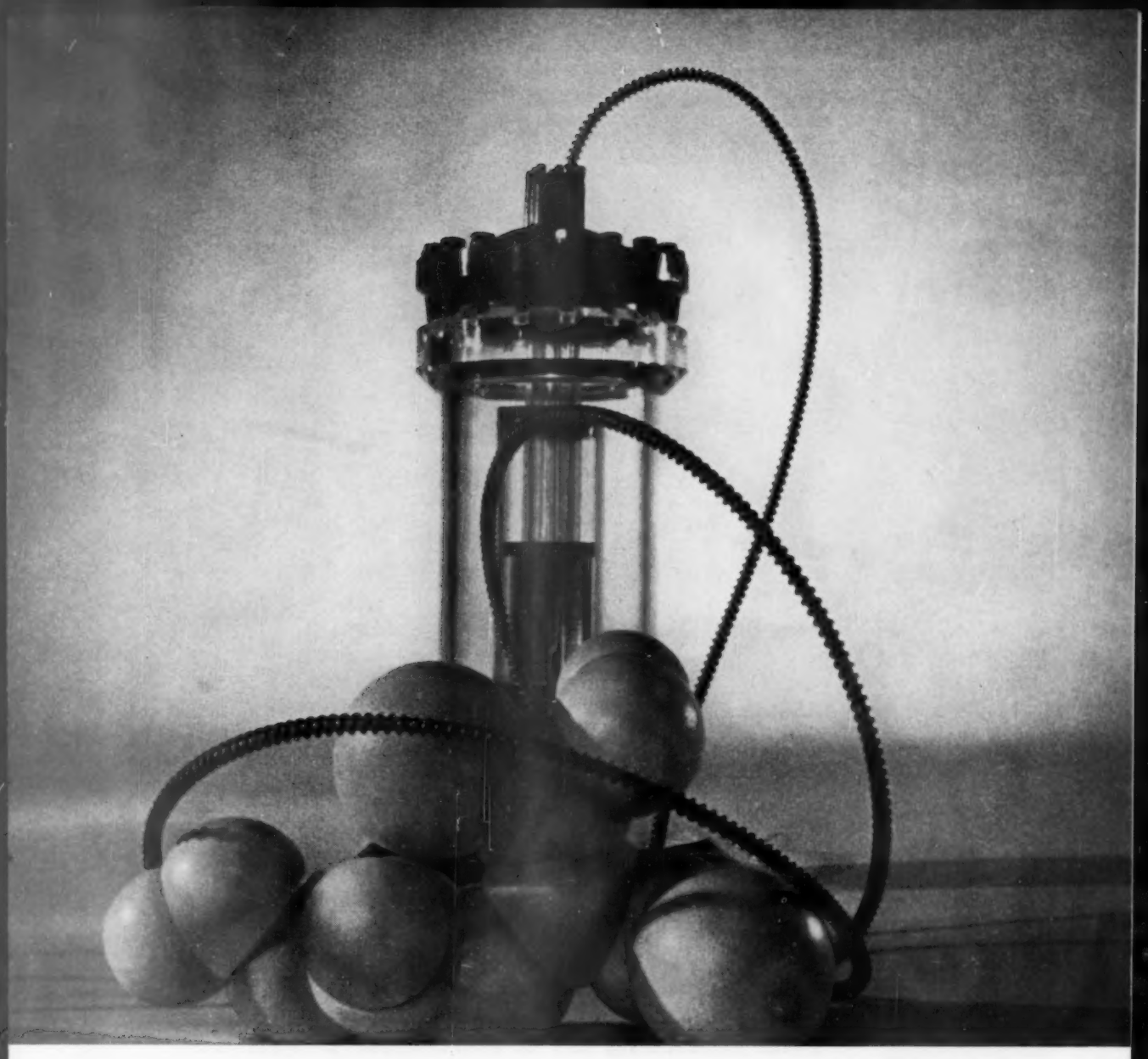

How to remotely position radiation detecting elements in core to ¼" at 50 feet. Or . . .

. . . how to remotely operate high torque valves from 150 feet. Or, remotely position radiation sources in hot cells within ±1/16". Or, simplify remote operation, increase personal safety and speed handling of critical materials . . . with cable systems that efficiently bend to meet any physical characteristics of reactor construction.

You can do all of these *and more* with TELEFLEX systems featuring TELEFLEX cable with its exclusive helix design. No other system has opened such opportunities for *new* methods of remote control, positioning, manipulating or measuring in the nuclear field. TELEFLEX is the only cable that can be driven in tension *and* compression, continuously and for unlimited distances. It also offers high accuracies; drives of slow or fast speeds; operation in extreme temperatures and high radiation areas . . . with no disruption of reactor performance or downtime.

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TELEFLEX SYSTEMS offer unequaled design flexibility because they are the only systems to offer all three types of mechanical motion...

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*$4,000 PER KILOWATT OUTPUT
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Television is a vital technique in the operation of gas-cooled reactors. The type of camera shown is in regular use at Calder Hall Nuclear Power Station, England; it carries its own lighting, and, in addition to visual inspection of the reactor interior, permits the removal of objects from the reactor using the special grab attachments. All the camera facilities are controlled remotely.

The camera functions satisfactorily with radiation dose rates greater than 10^5 Rads. per hour; cooling gas, carried to the camera by the supporting hose, allows operation with ambient temperature of 150°C.

Direct experience of such conditions over a number of years has enabled Pye to design cameras that will withstand high levels of nuclear radiation, temperature and pressure. Models can be supplied for use in water-cooled reactors. If you have any specialised television requirements, contact Pye Ltd., and avail yourself of their experience.

This console gives complete remote control of the camera. It carries the picture monitor and the control unit.

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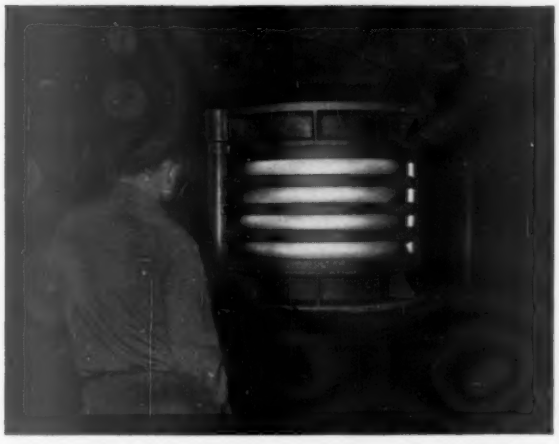
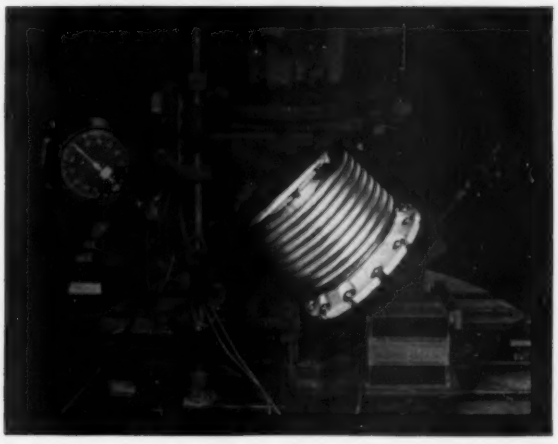
4 WAYS to get maximum reliability in expansion joints



1 Insist that the corrugated bellows be hydraulically formed. The reason is simple. Whenever bellows are formed by circumferential welding . . . whether by edge, seam or fillet welding . . . they will always be subject to premature failure because of stress concentrations at the welds.



2 Be sure the manufacturer maintains a continuous and comprehensive program of endurance testing. This is basic, because of the many variables that affect expansion joint life. Accurate determination of expansion joint life expectancy can only be determined by cycling to destruction.

3 Demand proof that the manufacturer can produce longitudinal welds in the corrugated bellows having the same strength, physical properties and thickness as the parent metal . . . without grinding. A weld that is hard to find is a ground weld. Variations in weld thickness set up points of stress concentration . . . opening the way for premature failure.

4 Check the ability of the manufacturer to supply a team of *competent* design and application specialists to work with your engineers. Check their specific experience in handling critical, complex applications in your field . . . complete to the record of successes or failures behind them, and details of how this experience will be brought to bear on your problem.

At Zallea, none of the many factors affecting expansion joint reliability are left to guesswork . . . including the four vital ones above.

This is reflected in these facts. Zallea material specifications are the most exacting in the industry. Zallea expansion joints are hydraulically formed. Zallea advanced welding techniques insure welds having the same thickness, strength and physical properties as the parent metal. Zallea has done more cyclic testing to destruction than all government agencies and industrial firms combined. Zallea has produced more expansion joints than any other manufacturer . . . offers more application engineering experience.

For all the facts, write for Catalog 56. Zallea Brothers, Taylor and Locust Streets, Wilmington 99, Delaware.

Zallea for maximum reliability

ZALLEA BROTHERS, Wilmington 99, Delaware • World's largest manufacturer of expansion joints

22 types of SAFETY ENCLOSURES for handling hazardous substances

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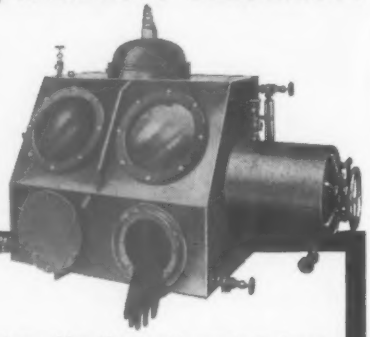

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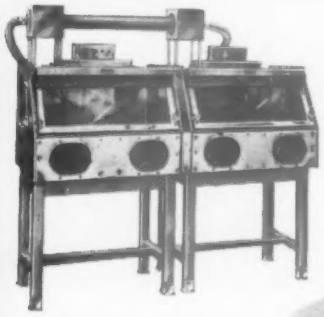

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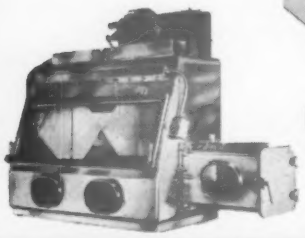

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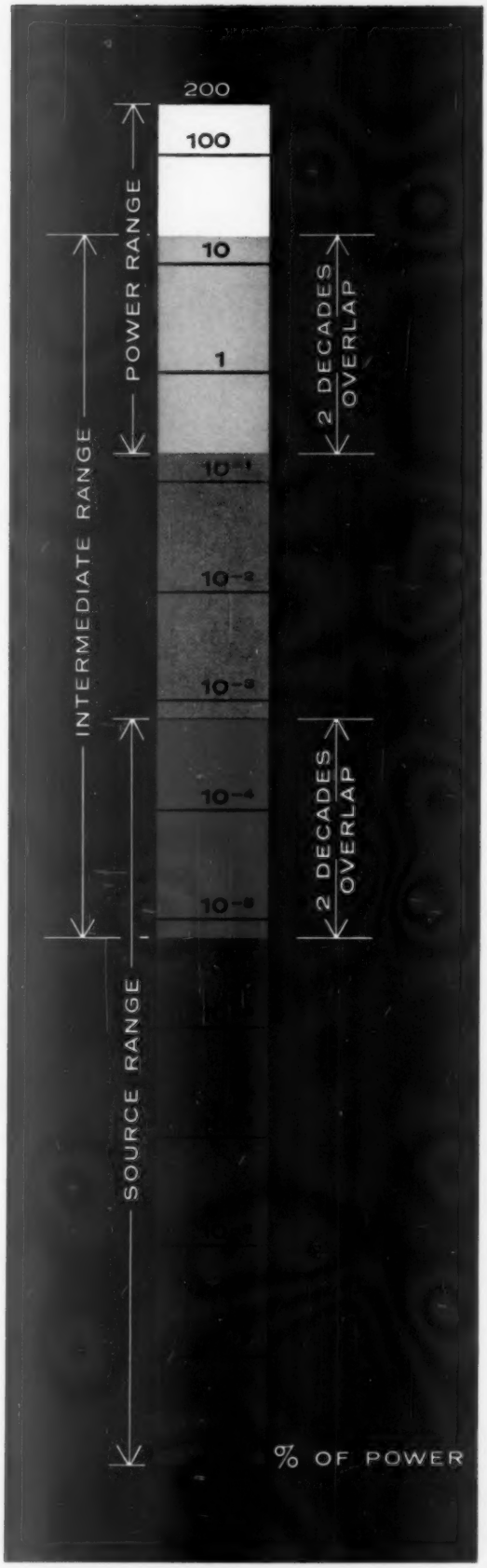

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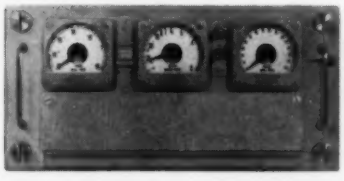

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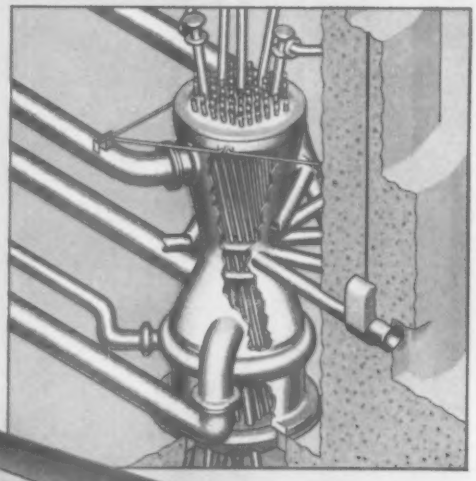

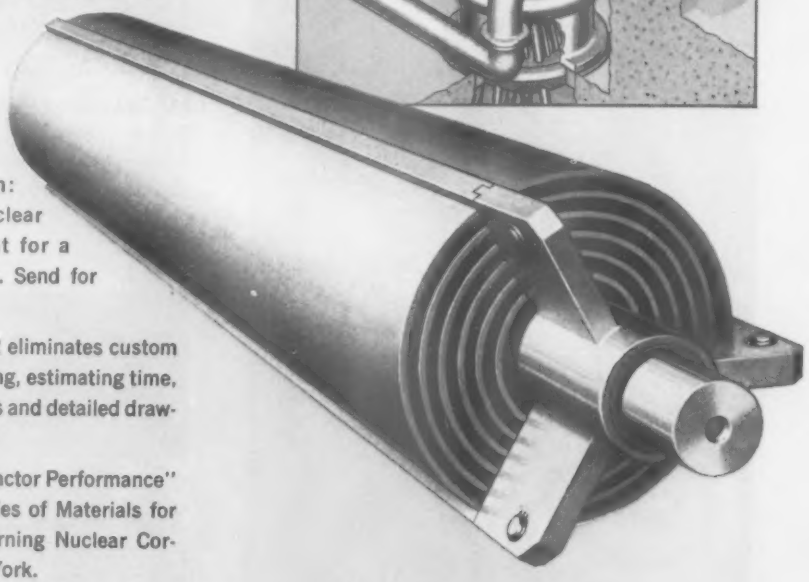

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Write for "Nuclear Fuels: Key to Reactor Performance" and "Physical & Engineering Properties of Materials for Nuclear Fuel Elements." Sylvania-Corning Nuclear Corporation, Bayside, Long Island, New York.

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Estimated Costs for Advanced Concepts

	PWR	*BWR*	*OMR*	*HWR*	*Coal Plant*
Power [Mw(e)]	236	306	300	221 (207)§	
Capital Cost [$/kw(e)]	252 (247)§	290 (301)	237 (232)	321 (322)	
	Power Costs [mills/kwh(e)]				
Fixed charges (14%, capacity)	5.1	5.4	4.7	6.4	3.3
Heavy-water inventory (12.5%/year)	—	—	—	1.5	—
Fuel-cycle costs	2.7–3.1*	2.7–3.1*	2.5–3.0*	2.0–3.0†	3.3††
Operation and maintenance	0.5	0.5	0.5	0.7	0.2
Organic or heavy-water make-up	—	—	0.6	0.2	—
TOTAL POWER COST [Mills/kw(e)]	**8.3–8.7** (8.2)§	**8.6–8.8** (9.3)	**8.3–8.8** (8.1)	**10.8–11.8** (11.0)	**6.8**

* For burnups of 13,000–10,000 Mwd/T. † For burnups of 7,500–5,000 Mwd/T.
†† For fuel costs of 35¢/10^6 Btu.
§ Numbers in parentheses are as reported by contractors (before AEC adjustment).

Advanced Reactor Studies

PLANT DESIGN STUDIES recently completed on advanced versions of four reactor concepts* find that plants starting construction in 1960 could include significant advances in engineering over existing versions (*see p. 60*). Although these advances give improved performance for each system, economic calculations predict that none of the reactors studied is likely to compete with conventional plants of the same size in any area of the U. S. The four concepts—pressurized water (PWR), boiling water (BWR), organic cooled (OMR) and heavy-water moderated (HWR)—all come out with predicted power costs of about 1 mill/kwh above the competitive rate (see table).

The first three of these concepts were selected by the AEC for study as showing the greatest potential for early development of economically competitive nuclear power. The fourth concept was selected because it uses natural uranium as a fuel (*see p. 63*).

The studies investigated the present status of the concepts with only minor attention to future potential. Essentially each study team tried to answer for its reactor concept the question: What would be the specific design improvements, plant size and estimated costs for the most economical power station that could start construction by July, 1960?

The PWR, BWR and OMR studies were set up with identical assumptions about plant site, expected life (30 yr), load factor (80%) and other ground rules. Although the assumptions for the HWR differed somewhat from these, the estimated costs in the table have been adjusted to place the optimum-size plant design for this concept on a comparable basis.

Also the data reported by all the contractors have been adjusted by the AEC to eliminate differences in interpretation of the ground rules on such things as pricing policies, construction schedules and indirect construction costs. However, no adjustments were made to compensate for differences in design conservatism (e.g., canned-rotor pumps for BWR, shaft-seal pumps for PWR).

An evaluation of the studies prepared by the AEC for the JCAE† reached these conclusions:

> " . . . there is no major difference in the cost of power to be expected among the PWR, BWR or OMR as designed.
> "The estimated power cost from the HWR is at least 1 mill/kwh above that of the other three systems. The use of enriched uranium in this reactor, which was designed for natural uranium, would reduce the cost only a few tenths of a mill/kwh.
> "For the BWR and OMR, the size chosen [300 Mw(e)] is probably the optimum size for lowest power cost within the limitations of current turbine technology.
> "[We believe] that the PWR [236 Mw(e)] and HWR [221 Mw(e) adjusted] would show further cost reductions if larger sizes were built."

It is estimated that a 300 Mw(e) PWR would produce power at a cost of about 0.7 mill/kwh below that shown in the table. The AEC pointed out in its report, however, that the technical feasibility of a 300-Mw(e) PWR is uncertain and would require a large research and development program. The power from a 300-Mw(e) HWR is estimated to cost approximately 1.0 mill/kwh less than shown.

* Study contractors were: Pressurized Water—Stone and Webster Engineering Corp., assisted by Combustion Engineering, Inc. (TID-8502, 3 parts); Boiling Water—Ebasco Services, Inc., assisted by the General Electric Co. (TID-8500, 3 parts); Organic Cooled—Bechtel Corp., assisted by Atomics International (TID-8501, 5 parts); Heavy Water Moderated—Sargent and Lundy Engineers, assisted by Nuclear Development Corp. of America (TID-8503, 2 parts).

† AEC Summary and Evaluation Report of Four Power Reactor Design Studies, TID-8504 (May, 1959).

Advanced Power Reactor Studies—

Engineering Comparisons

The three concepts that are related to current reactor projects are improved in core performance and thermal efficiency over their older counterparts. More effort on primary coolant systems might yield additional savings

S. BARON, *Burns and Roe, Inc., New York, New York*

OF THE FOUR power reactor concepts studied, three (PWR, BWR and OMR) are related to reactors that are near or under construction (Yankee, Dresden and Piqua). Comparison of these advanced concepts with their present-day counterparts (see table) reveals substantial engineering improvements in each of the three instances. If we grant the feasibility of the suggested improvements, none of the three can be counted out of the economic competition (see p. 59).

Interestingly enough, the PWR and BWR appear to be converging upon one another, with boiling tolerated in the PWR and less boiling considered in the BWR. Apparently the best features of these two reactors are destined to be combined into a single reactor type.

The advanced PWR and BWR were increased in size by a factor of 1½–2 over the plants presently under construction. On the other hand, the advanced OMR is about 25 times greater in size than the Piqua plant. There is, then, a greater degree of uncertainty in the design and cost of the advanced OMR because of this large extrapolation.

The advanced-concept studies reflect their best thinking in designing the power-conversion cycles for higher efficiency and reactor cores for higher performance. The improvements quoted in power densities and thermal efficiencies for these reactors open the way to competitive nuclear power within a 5–10-year period should these plants be constructed and their estimated costs confirmed.

This seems true in spite of the fact that the primary heat-removal systems, which contribute greatly to the high capital costs of nuclear plants, were not appreciably advanced in these studies over those of plants under construction. Further studies should be made to reduce the cost of these systems by selecting lower-cost materials and more conventional equipment designs.

Plant Efficiency

The advanced PWR showed the greatest improvement in efficiency; Stone and Webster–CE increased steam generating pressure to the 1,000-psia level of the BWR and, in addition, arranged to reheat the dried steam with throttle steam after the first moisture separator. They also considered changes in the turbine design to improve the over-all efficiency of the plant. As a result, they anticipate an efficiency for the advanced PWR comparable to that of present fossil-fuel plants of *higher* steam pressure and temperature. (This is possible because in fossil-fuel plants 10–15% of the heat is lost to stack gases.) These changes in the PWR maintain its competitive position with the other reactor types.

In the advanced OMR, improved heat transfer in the core (owing to a new fuel-element design) allows higher coolant and steam temperatures. These increases together with an increase in steam pressure are the reasons for the efficiency gain of the advanced OMR over that of the Piqua plant.

Optimization studies for the advanced BWR recommended the same steam conditions as those adopted for Dresden. Although decreasing the number of feedwater heaters and final feedwater temperatures tends to reduce plant efficiency, the net result shows a gain because of (a) the decreased condenser pressure, (b) recovery of heat from the hydrogen and oil coolers, and (c) an improved turbine efficiency (resulting from an improved design and increased size).

In contrast, the advanced PWR and OMR improve their efficiencies by increasing the number of heaters and the final feedwater temperatures as well as recovering heat from the hydrogen and oil coolers.

In all instances the station auxiliaries of the advanced concepts consume a

Design Parameters: Advanced Concepts Compared with Existing Reactors

	PWR		*BWR*		*OMR*	
	Yankee	*Advanced*	*Dresden*	*Advanced*	*OMRE-Piqua*	*Advanced*
CORE DESIGN						
Core dimensions (ft)						
diameter	6.2	8.2	10.5	11.1	4.5	11.0
height	7.5	9.5	10.0	11.3	4.5	12.0
Avg. specific power [kw(th)/ft³ of core]	1,810	1,430	750	1,026	660	880
Max. heat flux (Btu/hr/ft²)	450,000	296,000	346,000	—	218,000	94,000
Avg. heat flux (Btu/hr/ft²)	87,000	82,000	94,660	108,400	59,000	39,500
Avg. burnup (10 Mwd/ton U)	8.2	13	10	12–15	3–4	5.10
Initial enrichment	3.0%	2.6% inner zone 3.4% outer zone	1.5%	1.9%	1.8%	2.5%
Excess reactivity, cold clean core, $\frac{\Delta k}{k}$ (%)	18.8%	9.5%	11.6%	29%	10.7%	12.6%
Fuel charge (metric tons)	26	53	60	64	66	52
Moderator/fuel ratio	3.03	2.3	2.17	2.5	—	2.9
Fuel						
Type	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Cladding	ss	ss	Zr	ss in 1st core, Zr thereafter	ss	Sint. Al
Cladding thickness (mils)	21	22	30	25	—	15
Shape	rod	rods	rod	rod	plate	rods
Dimensions (in.)						
diam or width	0.337	0.44	0.56	0.45	0.132	0.33
length	90	113	117	130	54	144
Control rods						
Shape	Cruc.	rods	Cruc.	Cruc.	rod	Cruc.
Poison	Ag-In-Cd	Ag-In-Cd	Ag-Cd	boron	boron	boron, Eu_2O_3
HEAT-DISSIPATION DESIGN						
No. of coolant passes	4	4	4	4	2	4
Coolant	H_2O	H_2O	H_2O	H_2O	Santowax R	Santowax R
Total coolant flow (10^6 lb/hr)	37	45	25.6	35.4	6.6	54.5
Reactor inlet temp (°F)	486	582	504.8	506	575	550
Reactor outlet temp (°F)	524	618	543.2	543.4	615	675
Operating pressure (psia)	2,000	2,000	1,000	1,000	35	45
Reactor vessel dimensions						
Internal diam (in.)	109	126	146	147	54	204 & 162
Height (ft)		32	40.5	46	28	67
Material	304 ss clad carb steel	304 ss clad low-alloy steel	304L ss clad carb steel	304 ss clad carb steel	½% Mo 1% Cr	low-alloy steel
Thickness (in.)	8	9	5.625	5.4	1	1.5–2
Coolant pumps						
Number	4	4	4	4	4	4
Power/pump (hp)	1,500	500	600	250	—	1,500
Type	canned	controlled leakage	canned	canned	process	process
Material	304 ss	304 ss	304 ss	304 ss	carb steel	400 series ss impellers
Piping						
Diam (in.)	20	22	18–22	22–24	16	30
Material	304 ss	304 ss	304 ss	304 ss	carb steel	carb steel
Steam generator						
Number	4	4	4	4	2	4
Type	Vert U-tube	Vert U-tube	Vert U-tube	Vert U-tube	Shell & tube	Horiz U-tube
Material	304 ss	304 ss	304 ss	304 ss	carb steel	low-carb steel
POWER DATA						
Reactor output [Mw(th)]	482	685	626	980	45.5	962
Gross generator output [Mw(e)]	145	248	192	320	12.5	313
Net station output [Mw(e)]	134	236	180	306	11.4	300
Net thermal eff. (%)	27.8	34.5	28.8	31.2	25.1	31.2
Station aux. power (%)	7.6	4.8	6.3	4.4	8.8	4.2
Steam-turbine conditions	465 psia 459.6° F	1,000 psia [184 psia 518.4° F] (reheat)	965 psia 475 psia	965 psia 457 psia	430 psia 550° F	590 psia 650° F
Condenser pressure (in. Hg abs)	1.5	1.5	2.5	1.5	1.5	1.5
No. of feedwater heating stages	3	4	4	4	4	5
Final feedwater temp (°F)	340	375	405	325	274	400

smaller fraction of the total power than their present-day counterparts. This would be expected from the increased sizes; however, the advanced PWR and OMR show unusually low values.

Core Design

A second common objective—to get as much heat as possible out of cores limited in size by the practical dimensions for reactor vessels—led to a number of advances in core design. In the advanced PWR, a two-zone core (2.6% enrichment in the inner zone and 3.4% in the outer zone) reduced the maximum-to-average power ratio to 2 from a previous 3–5. A high average coolant temperature was obtained by permitting local boiling in the core with the reactor outlet temperature only 5° F below the saturation temperature for the minimum primary-system pressure. The water-to-uranium ratio, lower than that of Yankee and other PWR reactors, also permits high-power generation.

The increase in specific power of the advanced BWR over Dresden results from a combination of factors. The average steam volume fraction of the advanced type is 18% rather than 45% in Dresden. Further, the hot-spot and hot-channel factors were chosen as small as feasible with a minimum burnout factor of 1.5. (The minimum burnout factor is the minimum ratio of the heat flux to cause burnout divided by the actual heat flux under the worst combination of operating conditions.) The burnout factor for the advanced PWR was 2.9. The stainless cladding of the fuel in the advanced BWR serves as a temporary poison in the initial core and flattens the peak-to-average heat flux. The average burnup is 10,000 Mwd/ton at the start and about 12,000 Mwd/ton after fuel replacements, which will take about 4 years. When enough highly irradiated elements are available to flatten the power, the stainless-steel poison can be eliminated; the intent then is to shift to zirconium fuel cladding and operate at 15,000 Mwd/ton.

The advanced OMR achieves high power densities with small-diameter fuel rods that have extended surfaces and a core design that has a peak-to-average heat-flux ratio of 1.5. The flux at the core center is flattened by carefully specifying the cruciform control-rod size and spacing. The average burnup is expected to be 10,000 Mwd/ton in the initial core with a lifetime average burnup of 15,000 Mwd/ton for later cores. The minimum burnout factor for the advanced OMR is 2 with local boiling in the hottest channels considered acceptable.

All the advanced concepts use uranium-oxide fuel. (Uranium metal can be used in the OMR and is found to give comparable costs if burnups of 5,000–10,000 Mwd/ton can be achieved.) The fuel is rod shaped in all the concepts. The OMR rod has the smallest diameter because of the poorer heat transfer of the Santowax compared with that of water. Cladding the OMR fuel with extended sintered aluminum improves the heat transfer to an extent that permits the large heat output quoted for the 11-ft-diam by 12-ft-high core.

Both stainless and Zircaloy cladding were studied for the water reactors; stainless was selected finally for the advanced PWR and Zircaloy for the advanced BWR. The difference between the two materials for the PWR is small enough to warrant keeping the selection open for further analysis.

Zircaloy cladding was selected for the advanced BWR because it gave lower fuel costs; however, the first core would be stainless to flatten the flux during the initial operation.

Similar to the Yankee design, the reactor-control poisons for the advanced PWR are silver, indium and cadmium. The advanced BWR uses boron-stainless for the initial core, and the advanced OMR europium oxide–boron. The BWR and OMR have the control rods driven from the reactor bottom while the PWR still uses top drives.

Heat-Removal System

The heat-removal systems of the advanced water-cooled reactors do not show any significant design improvements over those presently under construction. The basic designs of Yankee and Dresden have been adapted with only minor changes because of increase in size. All the concepts have four loops, just like Shippingport.

The water-cooled reactors have adhered to 304 stainless steel in the material specifications for the primary system. Carbon-steel or stainless-clad piping was considered but not adopted for the final design. The limited experience with these lower-cost substitutes has discouraged their use in large plants even of the advanced types. Yet fabrication experience and laboratory results give every reason to expect that carbon steel or stainless-clad piping would prove successful.

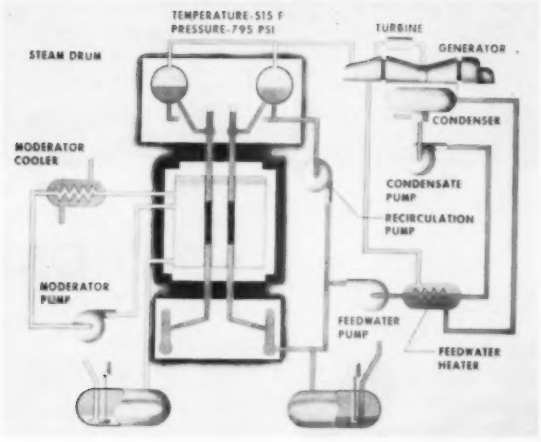
The advanced BWR still uses canned-motor pumps in spite of their high initial cost because they have zero leakage. The water-injection controlled-leakage pumps suggested for the advanced PWR promise respectable savings and improvement in efficiency. It would seem we have enough operating experience with heterogeneous water reactors to question the need for zero-leakage pumps when controlled-leakage pumps would give appreciable savings.

The vertical U-tube steam generators developed for the naval reactor program are also used in the advanced PWR and BWR. These heat exchangers are compact and have proved successful in operation. It may be, however, that the high cost of these compact vertical steam generators is not justified in a stationary nuclear power plant. Probably one reason these exchangers cost so much is that they have developed under the stringent specifications of the Navy. Steam generators based on ASME coding rather than military specification could be built for much less.

Limits on the fabrication of reactor vessels have in turn limited the size of the cores of the advanced water-cooled reactors. Railroads can not transport reactor vessels with diameters greater than 12 ft. (If the vessel is shipped with its nozzles, it must have an even smaller diameter; however, it is possible to weld and stress-relieve the nozzles in the field.) Even when water transportation is feasible, the vessel diameters with nozzles are limited to 15 ft by the size of the shop stress-relieving ovens.

In contrast the low-pressure OMR vessel can be fabricated in the field without difficulty.

The advanced OMR is difficult to compare with OMRE and Piqua because of the large difference in size and design. Even so, we can see that, with reference to these reactors, so many parameters have been changed that the concept is much more advanced than are the other studies in relation to their respective prototypes. Although the extrapolation in the advanced OMR is great, the equipment of the heat-dissipation system is still conventional and should offer no difficulties.



BOILING D_2O REACTOR with pressure-tube core was chosen by S&L–NDA as best of D_2O-moderated, natural-U family. Design satisfies ground rules of study and will be able to take advantage of most promising technical advances

Advanced Power Reactor Studies

D_2O–Natural Uranium Reactor

G. F. HOVEKE
Sargent & Lundy, Chicago, Illinois

J. DeFELICE
Nuclear Development Corp. of America, White Plains, New York

THE REACTOR CONCEPT studied by Sargent and Lundy and NDA—D_2O moderated, natural U—differs from the other three concepts (see pp. 59 and 60) in that no reactor of this type is currently under construction in the U. S. The reasons for interest in this concept center on the advantages of natural-U fuel versus enriched-U fuel; D_2O-moderated reactors that operate on natural U have these advantages: they

- are independent of government-produced or -controlled enriched fuels,
- can take advantage of the competitive natural-U fuel market,
- would have no conflict with potential military demands for enriched fuels,
- could, at option, decide not to process spent fuel, and
- reduce the continuing currency demand on foreign countries for purchase of enriched fuel.

Under ground rules similar to the other three studies, S&L–NDA chose a direct-cycle boiling D_2O concept with a pressure-tube core (see figure). This design was considered the best solution to the assignment originally posed by the AEC contract—to make a comparative evaluation of all D_2O moderated reactors that can operate on natural-U fuel and to prepare a conceptual design of a minimum-sized prototype of the most promising system operable on natural U. Under AEC ground rules for this study, the design was based on technology currently available and development which could be undertaken in parallel with design and construction of a prototype with startup by 1963.

We compared pressure-tube and pressure-vessel reactor concepts and considered H_2O, D_2O, organic and gaseous coolants in some detail. The principal design limitation proved to be the present-day inability to make accurate predictions of the reactivity for natural-U systems; as a consequence there is uncertainty about what materials are acceptable for fuel composition, fuel cladding, pressure tubes and core structure.

We found pressure-tube systems to be potentially the most economically attractive long-range members of the D_2O-moderated reactor family that can operate on natural U in large plants. The most promising coolant in the long range for these systems appears to depend on the final outcome of reactivity, materials, and heat transfer developments.

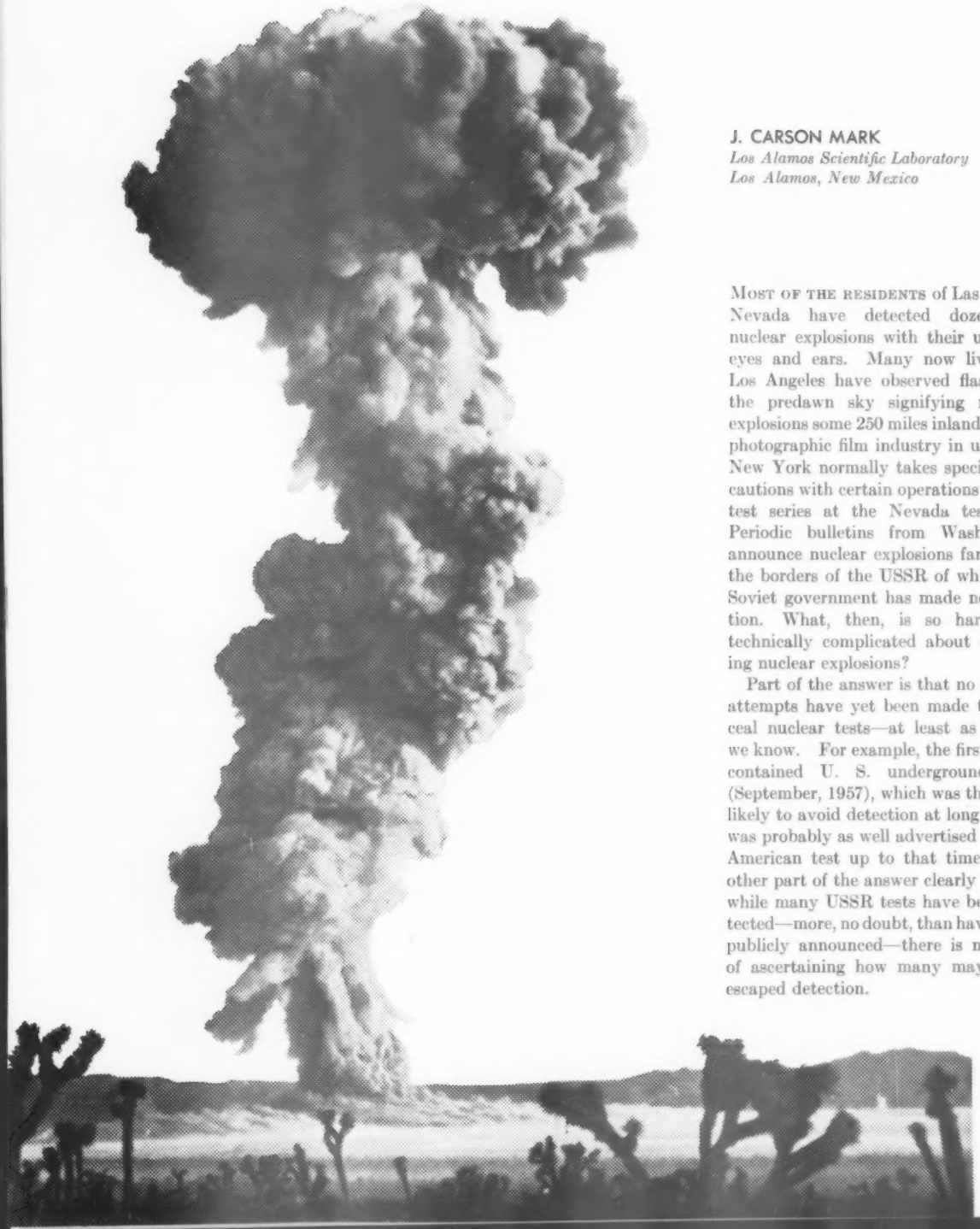
The prototype design is a 70-Mw(e) reactor with Zr-2 pressure tubes through an aluminum calandria and natural UO_2 fuel clad with Zr-2. Some principal characteristics are:

Coolant inlet temperature	498° F
Coolant outlet temperature	515° F
Exit-steam quality	14%
Exit pressure	795 psia (dry saturated)
Moderator temperature (max)	200° F

The research and development program, including the cost of the facilities to perform large natural-U critical experiments, would come to $10.7 million.

A first-generation 200-Mw(e) plant of this type would yield power at an estimated 11.7 mills/kwh with natural U or 11.6 mills/kwh with slightly enriched U. These figures include heavy water at $28 per pound and 11.5% per annum. Specific potential-cost reductions foreseen for subsequent units of the same type would total about 3 mills/kwh.

The Detection of Nuclear Explosions



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MOST OF THE RESIDENTS of Las Vegas, Nevada have detected dozens of nuclear explosions with their unaided eyes and ears. Many now living in Los Angeles have observed flashes in the predawn sky signifying nuclear explosions some 250 miles inland. The photographic film industry in up-state New York normally takes special precautions with certain operations during test series at the Nevada test site. Periodic bulletins from Washington announce nuclear explosions far inside the borders of the USSR of which the Soviet government has made no mention. What, then, is so hard and technically complicated about detecting nuclear explosions?

Part of the answer is that no serious attempts have yet been made to conceal nuclear tests—at least as far as we know. For example, the first fully-contained U. S. underground test (September, 1957), which was the most likely to avoid detection at long range, was probably as well advertised as any American test up to that time. Another part of the answer clearly is that while many USSR tests have been detected—more, no doubt, than have been publicly announced—there is no way of ascertaining how many may have escaped detection.

Methods Available For Detecting Nuclear Tests

Location of test	Radioactive debris	Air-acoustic	Hydro-acoustic	Seismic	E-M waves	Visible light	X-rays	Neutrons, γ-rays
Underground	✓			✓				
Underwater	✓		✓	✓				
Surface and lower atmosphere	✓	✓		?	✓	?	?	
Upper atmosphere ($\geq$ 50,000 ft.)	?	?			✓	✓	✓	✓
Outer space					?	?	✓	✓
Limitations on usefulness	underground test requires on-site inspection	periodic windstorms	earthquake background	earthquake background	severe natural-disturbance background	periodic cloud cover; attenuation in air (for low-level tests)	can be shielded	spread out in time (low intensity)

Moreover, the situation will be very different under an international agreement to ban or limit tests. There will be a large interest in making certain that the agreement is honored; anyone considering a clandestine violation would take the greatest pains to make detection as difficult as possible.

It is with this situation in mind that we shall here discuss the means of detection of nuclear explosions. While we shall sketch out the proposals made at the International Conference at Geneva during the summer of 1958 for a world-wide detection system of stated capability, we shall not discuss the proceedings of the Conference, or the subsequent political developments. Nor shall we attempt to assess the possible role of conventional "intelligence" operations as they might bear on detecting violations. Most emphatically, we shall not tangle with the pros and cons of whether or not an international agreement to limit or forego further testing is a good idea. This is an area in which the level of illumination decreases with the degree of heat, and some time will yet be required before these things can be seen clearly.

Finally, since the larger the explosion, the more easy it must be to detect, we shall consider mainly explosions in the range of one to a few kilotons.

Explosion Characteristics

The chief characteristic of practical importance for nuclear weapons is their very large energy release per unit of required weight. To accomplish this release during the explosion the energy must be developed in an extremely short time; as a result the materials of the device will be brought initially to a very high temperature. Typical times for the major part of the reaction are of the order of 10^{-7} sec or less. Temperatures will range from several hundred ev (1 ev = 11,600° K) on up into the kilovolt range, at least for the material necessarily involved in the device proper.

The explosion will be accompanied by a pulse of prompt neutrons and gamma rays of about the duration indicated above. By a somewhat arbitrary definition, a kiloton of TNT is taken to be 4.2×10^{19} ergs,* which is about the energy released by 1.5×10^{23} fissions. Thus, the net production of prompt neutrons is around 2×10^{23} per kiloton of fission. The prompt gamma rays emitted are not usually those released directly in the fission process, because these are largely absorbed in the assembled fissile material, but are gammas from neutron capture in heavy elements or from inelastic scattering in the outer layer of material in the device. The numbers of prompt neutrons and gamma rays that actually leave the device depend,

* This is a kilocalorie per gram of high explosive. We are, of course, interested only in the energy available for explosive effects, and hence that which is released quickly. The assumption is not far astray for conventional explosives; but high explosive burned slowly releases more energy than this, and well-combusted coal releases several times more energy per gram. Actually, for convenience in handling on modern automatic computing machines, the arbitrary constant 4.2 is often replaced by the familiar and convenient constant $4\pi/3$.

About the Author

J. Carson Mark has been working at Los Alamos since 1946 on problems related to nuclear devices and their effects. He is currently the leader of the Laboratory's Theoretical Division, a position occupied by Hans Bethe during World War II. Mark was born in Canada in 1913 and received his Ph.D. in mathematics from the University of Toronto. During the summer of last year he served as a scientific advisor to the American delegation at the Geneva Conference of Experts on the Means of Detection of Nuclear Explosions.

of course, on its construction and the materials that surround it, and hence can vary considerably.

Fission products from the reaction provide delayed gamma rays, and emit about as many quanta in the first second as there are prompt neutrons. Because almost all of these appear after the material in the device has dispersed, the number of delayed gammas will be little affected by details of construction or modest attempts at shielding. The fission-product radioactivity persists through very long times; even quite small samples of the debris ($\sim 10^{-13}$ of the whole, or the residue from 10^{10} fissions) can serve to fix the fact and approximate time of a fission explosion many days after the event (provided the sample is not too badly fractionated or mixed with fission products from other sources). In addition to the fission products, other radioactive species may be formed by neutron reactions in the bomb materials or in the soil; but the nature and amount of these vary widely. Thermonuclear explosions, too, release fission products in appreciable quantities. Even the so-called "clean bomb" has been officially described as obtaining 5% of its energy from fission.

To complete our list of nuclear-explosion characteristics we should mention that the high pressures in the immediate neighborhood of a nuclear explosion and the high velocities imparted to the material of the device will drive a wave into any surrounding medium (whether earth, water or air) that progresses for a while as a shock wave, and later becomes an acoustic wave. This wave can serve as a signal of the explosion at large distances. At points close to the center of a nuclear explosion the pressures range from hundreds to many hundreds of megabars; material velocities are as high as 10^8 cm/sec. In some regions the energy in the radiation field equals or exceeds the material energy content.

INDICATIONS OF A NUCLEAR EXPLOSION

From what we have said so far, it is clear that radioactive debris is the only specifically nuclear indication of an explosion that is available for analysis at large distances (or at long times). Given a sufficient sample of debris, some properties of the original event may be reconstructed. Other indications of an explosion that might be available are the pressure waves in the surrounding medium or the ionizing or thermal radiation accompanying the event. In any case, we can begin to see that the problem of detection of nuclear explosions involves a rather small component of nuclear physics along with large components of meteorology, acoustics, seismology, electromagnetics and atomic physics.

We shall have to consider the various environments in which an explosion might be staged (lower atmosphere, high atmosphere, interplanetary space, underwater, underground), the signals that might be propagated (diffusion of radioactive debris, acoustic, visible, thermal or electromagnetic), the instrumentation that might be effective in recording these signals, and, finally, the various background noise levels and the problem of sorting out the signals of nuclear events from natural or man-made non-nuclear events.

Radioactive Debris

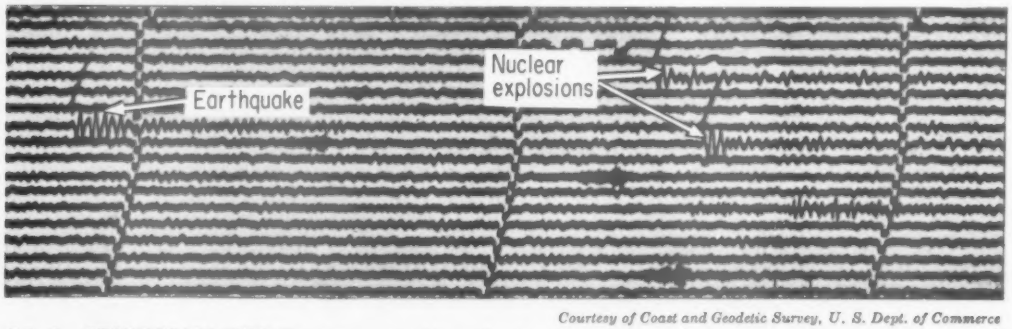
From a fully-contained underground explosion, the radioactive products, with the possible exception of the gaseous fission products, will remain close to the scene of the event (from a few meters up to a few tens of meters). Most of the direct by-products of the explosion will be trapped in the material that vaporized or melted during the explosion and will not move or diffuse away. The trapped debris remains as evidence for very long times, but can be detected only by sampling the materials within ten meters or so of the original position of the device.

From an underwater explosion, deep enough not to release much of the original bomb materials to the atmosphere, radioactive debris will appear in conspicuous and identifiable concentrations on the surface of the water at first. However, ocean currents will shift, disperse and dilute the debris, and after ten days or so it will be difficult to locate or identify.

Explosions that occur close to the surface of the earth will leave persisting records at the scene and also produce radioactive clouds in the air which can be detected at considerable distance, much in the nature of the situation referred to below.

An explosion in the lower atmosphere ($\sim$1 kt at an altitude of 10 to 20 $\times$ 10^3 ft) will leave a large part of its radioactive debris within the troposphere. An airplane flying below

Was It an Earthquake—or a Nuclear Test?



Courtesy of Coast and Geodetic Survey, U. S. Dept. of Commerce

FIG. 1. SEISMOGRAPH RECORD points up problem of separating nuclear tests from earthquakes. Seismograph at Fairbanks, Alaska picked up signals (indicated at right) from two nuclear explosions announced by U. S. as part of Pacific test series during summer of 1958. During hour-long interval (successive traces are 15 min apart) between planned tests, seismograph picked up third signal (left). Indistinguishable from signals at right, this signal is thought to be chance earthquake—but same pattern could result from Russian test

Detection System Proposed at Geneva

The official report from Geneva concluded that three main parameters characterize a network of control posts:

- The minimum yield of the nuclear explosion to be detected
- The number of control posts
- The probability of discriminating correctly between nuclear explosions and natural events, particularly earthquakes

An increase in the yield of the explosion or the number of control posts increases the probability of detection and identification and decreases the number of unidentified events which might be suspected of being a nuclear explosion.

The conference considered an underground explosion the hardest to identify; hence this type of explosion to a large extent determines the characteristics of the proposed network of control posts.

The network would include from 160 to 170 land-based control posts and about 10 ships. Of these 160–170 control posts, about 100–110 would be situated on continents, 20 on large oceanic islands, and 40 on small oceanic islands.

The posts in continental areas would be at spacings of about 1,700 km, except in areas with a history of seismic activity where the spacing would be about 1,000 km.

As to the posts located on islands, it appears possible to maintain the 1,000-km spacing in the main seismic regions, but in some ocean areas the spacing would have to be from 2,500 to 3,000 km.

The disposition of the continental posts would be: North America—24; Europe—6; Asia—37; Africa—16; Australia—7; South America—16; Antarctica—4.

According to the conference this network (supplemented with aircraft) would have:

- Good probability of detecting and identifying nuclear explosions with yields down to 1 kt, if they take place between the surface of the earth and up to 10 km in altitude; good probability of detecting, but not always of identifying, explosions that take place at altitudes from 10 to 50 km.
- Good probability of detecting nuclear explosions with 1-kt yield set off deep in the open ocean.
- Good probability of recording seismic signals from 1-kt nuclear explosions deep underground in continents.

However, the network would be unable to distinguish between underground explosions and some earthquakes. For instance it was expected that it could separate out 90% of the continental earthquakes equivalent to a 5-kt explosion but only a small percentage equivalent to 1 kt.

Although it was realized that the system would have great difficulty in obtaining positive identification of a carefully concealed underground explosion, there would always remain a possibility of detection of a violation by inspection.

In the New York Times, January 18, 1959, Hanson Baldwin reported that the Western delegation originally proposed a network of 650 stations, which was later cut back to the 170 mentioned above. The implication has been that the smaller network was accepted by the Western Delegation to fulfill the same function as the larger one. This, of course, is not the case. The 650-station network was supposed to discriminate between earthquakes and underground explosions down to the 1-kt level; the 170-station network was supposed to do this only down to the 5-kt level. The Nevada tests of fall 1958 indicate that these expectations were overoptimistic. Thus the 170-post system now appears to be as effective as intended only for somewhat larger underground explosions (15–20 kt, rather than 5 kt). The system proposed would still be capable of detecting and identifying 1-kt explosions in or near the atmosphere.

50,000 ft (with a filtering capacity of ~60 m³/min) can pick up the required sample size of 10^{10} fission products at distances of 2,000–3,000 miles from the event and at times up to 5–6 days after the event. Ground-based air-filtration plants with filtering capacities of 2×10^4 m³ of air per day can collect the required sample at distances of several thousand miles and at times of ten to twenty days after the event.

For explosions above 30,000 ft (above the tropopause) the collection of radioactive debris offers a less specific means of detection: the rates of exchange of matter between the surface and these altitudes are not clearly understood, and sampling at these higher altitudes is not done routinely.

At very high altitudes, although signals from the radioactive products may be available, evidence in the sense of collection and analysis of debris passes out of the present picture.

Air-Acoustic

The strong acoustic wave formed by an explosion in air propagates over large distances. In a homogeneous atmosphere, the amplitude of the pressure pulse is roughly proportional to the cube root of the energy release and inversely proportional to the distance. However, meteorological conditions cause atmospheric inhomogeneities that disrupt this simple behavior and signals can vary by as much as a factor of five up or down from a nominal value based only on the energy release and distance to the detecting station.

For a 1-kt explosion in air, the signal (overpressure in the first pulse) measured by microbarographs on the surface might typically be 10 dynes/cm² (10^{-5} atm) at a distance of 1,000 km. Although data on the signal variation with altitude is scant, it seems clear that an acoustic signal of about this size will result from explosions conducted anywhere between the surface of the earth and altitudes of 100–150 thousand ft. This type of signal is unavailable from explosions contained underground or underwater, is much reduced for subsurface bursts even if they break through to the atmosphere, and is again uncertain to unavailable at very high altitudes.

The statement that the pressure in the acoustic wave is proportional to the cube root of the yield divided by the distance was introduced by the Eastern Delegation early in the discussion at the Geneva Conference in the summer of 1958, and was the occasion of considerable debate. Although this scaling relation is reasonably good in an infinite homogeneous medium, it has rather little convincing relevance to the actual propagation of sound signals in air at large distances. The facts are that the atmosphere is two- rather than three-dimensional, is not homogeneous (its density, temperature and sound velocity vary considerably) and is usually involved in some complicated pattern of motion.

A simple model for wave propagation which takes into account the variation of sound velocity with altitude is discussed in the Appendix. It is this model that predicts 10 dynes/cm² pressure as a typical value at 1,000 km.

The upper-atmosphere winds in the middle northern latitudes blow from west to east during the months between October and March, and in the reverse

direction between May and August. In the interims, these winds are variable, unpredictable, or nonexistent. These seasonal variations can cause as much as a factor of five difference in the pressure at a given distance from an explosion of given energy; hence the 10 dynes/cm² estimated above for 1 kt at 1,000 km might vary between 2 and 50 dynes. This means that for detection purposes strong signals are available at long ranges down-wind, weak ones upwind, and intermediate ones in other directions. In the summer 1958 discussions at Geneva there was an initial tendency on the part of Eastern delegates to argue that there must always be some place "down-wind" where large signals (and large ranges of observation) would be available; but, since the location of the event can only be determined by triangulation from observation posts in a reasonably widespread net and since these cannot all be down-wind, the final recommendations assume that detection and location should be feasible in the in-between season when the upper winds are light and variable, which imposes the most restrictive conditions.

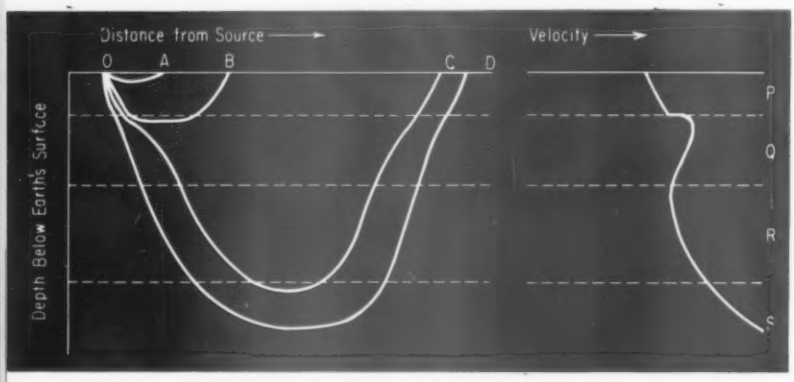


FIG. 2. EARTHQUAKE WAVES traveling by different paths through earth to point C may have similar travel times because of variation of wave velocity with depth (right)

Hydro-Acoustic

The "so-far" system of air-sea rescue, in which ships or planes can attract attention at ranges of thousands of miles by exploding a few pounds of high explosive at depths of a hundred meters, is enough to suggest that underwater explosions in the open ocean are easy to detect. Just as in the air, there is a sound channel in the ocean, because the sound velocity decreases with depth down to a few hundred meters (due to the increase in temperature) and then, at lower depths, increases (due to the increase in pressure). Bethe's two-dimensional model (see Appendix) estimates a pressure of 3.5×10^4 dynes/cm² at 1,000 km for a 1-kt explosion in water under the assumptions that the sound channel in water is about one kilometer in height and that the dispersion in sound velocity is about 2%.

From the magnitude of the signal it is clear that the detection of explosions in the open ocean is not a difficult problem. The problem is to make sure the signal was from a nuclear explosion rather than from a natural event, such as a submarine earthquake. Although the incidence of such events is not large, it is not negligible and is not well known. To identify a nuclear explosion as such it will be necessary to take samples of fresh radioactive debris from the ocean surface. Even after the event is identified as a nuclear explosion, the question would still remain as to who set it off. This uncertainty will come up in all cases where an explosion occurs far outside national boundaries and it may be necessary to depend on conventional intelligence agencies to determine the author.

Long-range hydro-acoustic signals are chiefly significant for explosions in the open oceans. There are a number of places where explosions could be conducted under water that would make detection by an oceanic hydrophone system difficult. These include inland waters, land-locked bays, atolls, and even locations in ocean waters where reflections and obstacles would complicate the transmission paths. However, the number of inland waters capable of containing significant nuclear explosions is limited, and the number of people in any country who would be willing to use them for that purpose must fringe on zero.

More importantly, inland or land-locked waters would be poor places to attempt to conceal an explosion; U. S. experiments have shown that there is a very good coupling between the energy of an explosion conducted deep under water and earth shocks that register on seismographs. In fact the seismic signals at a given distance would be larger from an underwater explosion than those from a similar explosion conducted underground. Thus, a seismic network could supplement a system of hydrophones in many cases where an oceanic hydrophone system would be ineffective.

Seismic

As a sound-conducting medium the earth is more complex and less well understood than either the atmosphere or the oceans. Most of our information about the elastic properties of the earth comes from seismological observations of the propagation of various types of earthquake signals over very long ranges. During the past 20–30 years we have supplemented this information, particularly over short distances, with observations on the seismic signals from chemical and nuclear explosions.

Seismologists generally agree that the earth (radius ~6,370 km) can be divided into three different zones: the surface layers—extending in depth to about 10 to 15 km beneath the oceans and to several tens of km beneath the continents and possibly consisting of two or more discrete regions whose thickness may vary as between mountainous areas and low lying locales and so forth; the mantle—extending from the surface layers to a radius of about 3,500 km; the core—the region inside the mantle. The velocity of sound generally increases with depth. For longitudinal waves (*P* waves) it is about 5.6 km/sec at the surface, 8 km/sec at the upper surface of the mantle, and reaches a maximum in the mantle of about 13.6 km/sec. At the surface of the core it drops sharply to about 8 km/sec and then increases again, on in to the center.

In detail, the variations of velocity with depth are much more complicated but are unimportant here beyond the general fact that the signals from a point source that arrive at some location on the surface are far from simple. Because of multiple reflections and refractions they arrive by many different paths. However, because the velocity generally increases with depth, rays are refracted back toward the surface. Where the velocity increases more steeply the refraction is stronger, so that such a layer introduces a focussing effect.

Among the reasons for being interested in the first signal to arrive (the longitudinal wave) is the fact that later-arriving signals have come by more complicated routes. Figure 2 shows, purely schematically, the paths that might be followed by the first-arriving signals, from a disturbance at point O to various points on the surface, for the indicated velocity distribution with depth. Out to some distance (A,B) the first signal has traveled only through the uppermost layer (P). Beyond that, the quickest path penetrates layer Q. At some range, such as C, two paths passing through R and entering S, one at a shallow angle and one at a steeper angle, may have similar travel times. Consequently signals will be anomalously strong near C and fall off rather rapidly at distances beyond C, such as D. In the earth, the path of the first signal will remain in the surface layer only for distances of a few degrees from the source. By about twenty degrees' distance ($\sim$2,200 km) the first signal has probably traveled along a path with a maximum depth of 500 km.

The amplitude of the vertical displacement in the P-wave as a function of distance from the explosion of 1 kt is shown in Fig. 3. The actual values are, of course, affected by the geological environment of the explosion; those shown are derived from the measurements made on the Rainier shot in Nevada (September 1957). Other environments might provide either larger or smaller signals. Water (which has already been mentioned) might provide signals as much as ten times larger; tuff, similar to that in which Rainier was fired, but containing less water, might provide signals smaller by a factor of two or three. Precise comparisons are, however, not available. To make things even more difficult, the amplitude also depends on the geological conditions at the detector site.

Irrespective of these problems of absolute amplitudes, Fig. 3 indicates that signals are stronger at distances of 2,000–3,000 km from the source than at the smaller range of 1,000–2,000 km. This undoubtedly is the result of the velocity variation in Fig. 2; indeed, a so-called "20° discontinuity" has long been familiar to seismologists in their observation of earthquake signals.

We have already mentioned that the longitudinal waves (P-waves) have the largest velocity of the various seismic waves, larger than the transverse waves (shear, or S-waves) or the surface waves. The P-wave thus provides the first available signal and, if its arrival can be clearly recorded at several stations, one has the basis for a fix on the source location. The later-arriving signals, even though their amplitudes may be larger, are of less use because, owing to the multiplicity of possible trajectories implied by the discussion of Fig. 2, their correlation by several stations may sometimes be difficult or impossible. There is also the point that late-arriving signals appear on a trace which has already been subjected to some disturbance.

An even more important reason for observation of the P-wave is the wish to determine the *direction of first motion*. An earthquake, normally caused by the faulting or slippage of large masses of rock, sends out rarefaction as well as compression waves—both of which transmit as longitudinal waves. A compression results in an initial upward displacement of the surface, whereas a rarefaction results in an initial downward motion. Earthquakes almost always transmit rarefactions in two roughly opposite quadrants. Explosions, on the other hand, would be expected to transmit compressions in all directions. Thus, the direction of first motion, observed in various directions from the epicenter (covering several quadrants), should distinguish between explosions and natural earthquakes.

The number of natural disturbances per year versus magnitude (on the Richter scale) is shown in Fig. 4, along with a rough correlation with the energy of the explosion which would give signals of comparable size. From this plot we see that between 5 and 6 thousand natural seismic signals per year might be comparable to that from an underground explosion with an energy of 5 kt. This estimate includes, at least in a preliminary fashion, the new data obtained from the U. S. explosions in Nevada in the fall of 1958. The data, both on the statistics of seismic signals and on the signals from underground explosions, is not by any means good enough to state a precise comparison. All that can be said is that the number of natural events with seismic signals of magnitude similar to those from a 5-kt explosion is probably between 3 and 11 thousand per year—and this considers only "shallow" earthquakes. (At present, from seismographic evidence alone, one can distinguish only between "deep" and "shallow" earthquakes, where "shallow" is anywhere between the surface and a depth of a few tens of km.) The size of this number emphasizes the need for a means of discrimination between earthquakes and explosions if seismic recording (the only means here considered) is to be used to monitor underground explosions. Only a detection system capable of ascertaining whether a given seismic disturbance did, or did not,

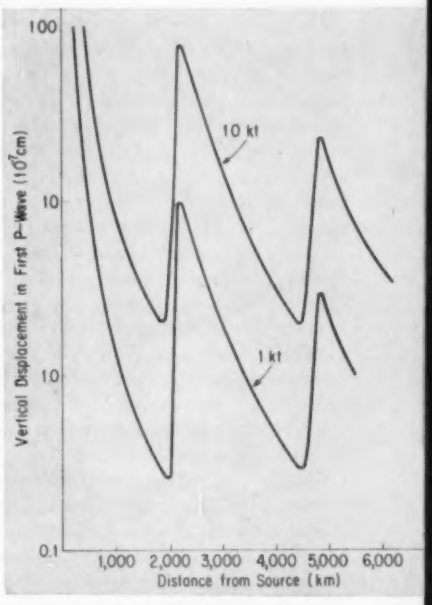


FIG. 3. DISCONTINUITIES in earthquake-signal amplitudes as function of distance from source arise because of variation of earthquake-wave velocity with depth (see Fig. 2)

send out compression waves in all directions can reduce to manageable proportions the number of events requiring on-the-spot investigation. Such an investigation of a suspected nuclear explosion would have to cover an area of the order of 100 km^2 (since this is the sort of accuracy with which the location of the source might be determined), and actual identification would require evidence of large-scale human activity and, finally, the demonstration of underground-contained radioactive debris.

Further analysis of the later-arriving wave trains in the seismic signals may turn up additional means of discrimination. One possibility which shows considerable promise concerns surface waves of very low frequencies (1/5 to 1/50 of a cycle per sec). These waves are so long (tens or hundreds of km) that they are relatively insensitive to the smaller-scale heterogeneities of the earth. It therefore becomes possible to understand their propagation and, in turn, the character of the wave train in such detail that subtle differences in sources may be deduced. Instrumental techniques recently developed at the Lamont Geological Observatory greatly improve the sensitivity of seismographs to these low-frequency waves. Further instrumental advances of this sort may be anticipated and there is much more to be learned about the seismic waves generated by earthquakes. The development of methods of discrimination between the long-period waves from earthquakes and explosions is, however, hampered by the limited seismic data from underground nuclear explosions.

Other aspects of the seismic signals from explosions which deserve mention are that the amplitude of the first motion would be expected (and from observation appears) to scale with a power of the yield between the two-thirds and first, at least for yields between 1 kt and a few tens of kilotons. The various forms of seismic waves attenuate strongly with distance, the higher frequencies more rapidly than the lower frequencies, so that at distances of a thousand or so km the important frequencies are in the range of a few cps, and their primary features depend on the mechanical and structural properties of the earth. The fraction of the total energy appearing in such long waves is, because of the short distance from the source at which the acoustic waves are established, rather small, being of the order of 10^{-4} to 10^{-3} of the energy of the explosion.

Our comments so far about seismic signals have had to do specifically with explosions that are completely contained. Signal strengths are much reduced when the explosion is close enough to the surface to allow venting; however, in this case, other types of evidence begin to become available. Seismic signals are, as has been mentioned already, generated by underwater explosions. They are also generated by air bursts that are not too far above the surface. In this latter instance, the seismic signal is not likely to be important for either detection or identification; but it may be useful in conjunction with other signals in determining location, time, and height of burst.

Electromagnetic

Nuclear explosions in the atmosphere radiate strong electromagnetic signals. A 1-kt explosion creates field intensities of tens of millivolts per meter at ranges of thousands of km. The mechanism that produces these signals is not understood in full detail; but it probably results from the current of Compton electrons created by the gamma-rays emerging from the explosion. The motion of these electrons away from the source, if the device were perfectly spherically symmetric and the atmosphere perfectly homogeneous, would not produce any electromagnetic radiation. However, on or near the surface, where many of the gamma-rays encounter the ground, there will be a net vertical component of current. Again, high in the atmosphere, where the gamma-ray paths are appreciably different in the two vertical directions, one would expect a signal. In the middle atmosphere, the signal from this latter mechanism should be reduced; this has been observed, though to a lesser extent than one might have expected. Of course, in practice, the gamma-ray flux from an exploding device is never fully symmetric because of the presence of auxiliary apparatus, external structure, or the carrying vehicle.

Under stated conditions of firing, the strength of the signal is only logarithmically dependent on the yield; presumably this is because the signal can originate only at distances from the source where the ionization level is low enough for the signal to transmit. As expected, heavy layers of shielding around the source can reduce the size of the signal; but, as suggested above, such a shield would have to be a significant number of gamma-ray paths thick to have a large effect.

Close to the source—up to a few hundred km, say—the signal retains very-high-frequency components characteristic of the time scale of the events in the explosion; but these high-frequency components attenuate rapidly, and the properties of the propagating medium (the well-known "sound channel" between the surface of the earth and the ionosphere) begin to determine the form of the signal transmitted to larger distances. The components available far out—essentially worldwide—are those in the range from a few up to a hundred kc.

At very high altitudes, the mechanism for creating electromagnetic signals is probably based on the fact that the upward-going quanta create no intense current (since they encounter no matter) while the downward-coming quanta are mostly intercepted at an altitude of 30 km or so. Hence we can expect useful electromagnetic signals from a 1-kt explosion up to altitudes of the order of 1,000 km.

All this is fine, except for the enormous number of natural electromagnetic phenomena ("atmospherics"). This number is not well known, but the rate of such events that might be recorded by several stations is expected to be from ten to a few hundred per sec. Most of these, by discrimination on signal strength, wave form and period, and so forth, could be identified as atmospherics rather than possible nuclear explosions; but with the analysis and discrimination techniques presently available the electromagnetic signal would not seem to provide a primary means of detection but rather a supplementary tool. It could be used, for example, to refine the estimates of the time of an event detected by an acoustic signal and improve estimates of the location; where events such as volcanic eruptions, meteor explosions, and so on might give an air-acoustic record similar to an explosion, the lack of an electromagnetic signal at the proper time and place could help rule out a nuclear explosion.

Visible Light

A significant fraction of the energy

of a nuclear explosion in the atmosphere radiates in the form of visible light. About one-third emerges ultimately in the form of quanta with wavelengths longer than about 3,000 A; about half of this is in the visible, the rest in the infrared. Since the major part of this radiation is emitted when the fireball is at rather low temperatures, the fraction appearing in this form does not depend strongly on the details of the device or on modest attempts at shielding.

The time scale for the visible radiation varies somewhat with altitude. At sea level the major part is emitted in a second or so from a typical 1-kt burst, and in about 10 sec from a 1-megaton burst, with rather little visible radiation at later times in either case. At high altitudes ($\gtrsim$100,000 ft, but still in the atmosphere), the very high peak intensity of visible radiation passes in a very short time (tens of millisec), but the time during which a conspicuous source of visible radiation is available may be relatively long. Outside the atmosphere (where the particle density in the surrounding medium is exceedingly low) there are no observations; but on theoretical grounds there should be a short sharp initial burst followed by a long sequel of low intensity.

The visible light from any device is easier to detect at long distances the higher the explosion (up to several hundred km altitude, at least, for distances of one to a few thousand km). Besides the inverse-square attenuation there is also atmospheric absorption ($\sim$5% per mile through clear sea-level atmosphere, or about 20% from the top of the atmosphere to sea level on a very clear day). The attenuation of a ray from the top of the atmosphere (10^3 grams) to the surface is less than that over a distance of 10 km on the surface. Permanent eye damage (burning of the rods and cones in a small area of the retina of an eye focussed on the scene of the explosion) was a possibility out to several hundred miles for the explosion high over Johnston Island in mid-August, 1958; but persons more than 50 miles away could have stared at a burst of the same size conducted on the surface without serious consequence.

Visible light may, then, provide a prominent signal. However, its range for ground observations of a low-altitude burst is only about 500 miles under favorable circumstances and this is not very useful. For ground observations of high altitude bursts, the range begins to appear useful. As a method of monitoring, however, it has the serious drawback of being affected by cloud cover.

Thermal X-rays

An appreciable fraction of the energy released in a nuclear explosion will flow away in the form of X-rays with energies of a few hundred volts or even a few kv. These will not go very far in a dense environment, so that in the lower atmosphere this transport mechanism merely serves to determine the early growth phase of the fireball. However, in the very high atmosphere, or beyond the tangible atmosphere, the X-rays will travel for large distances. In a vacuum, as much as 50% of the energy developed might escape in this form from the materials required for the explosion; hence X-rays provide a possible means for the detection of explosions conducted far outside the earth's atmosphere.

These X-rays could, of course, not penetrate the atmosphere, as could the visible light, and would have to be observed by instruments carried on satellites. For explosions not too far above the atmosphere, however, these X-rays impinging on the upper strata would be expected (as suggested earlier) to induce ionization leading to fluorescent or electromagnetic effects that could very probably be observed.

Neutrons and Gamma Rays

Although copious quantities of neutrons and gamma rays are emitted during a nuclear explosion, they too are not detectable at long ranges in a medium as dense as air. The radioactive products of neutron bombardment (C^{14} or activated elements in the soil) might be considered for explosions in the lower atmosphere or near the surface of the earth. Also, one might think about detecting explosions far from the earth by detecting the neutrons or gamma-rays directly. This again would require detectors stationed far out in the atmosphere.

Other Possibilities

Although there is little definite we can add, we should point out that this, or any discussion of this subject, cannot claim to be complete. There are probably other effects, or aspects of effects referred to, which could, after consideration, offer more promising handles than those mentioned. An (at present) rather hypothetical example might be the reflecting or refracting properties of ionized clouds as observed on long-range radar; or explosions might cause changes in the reflection properties of the ionosphere which could be observed by monitoring equipment such as radar or radio telescopes. As another example, since an explosion far above the atmosphere requires the launching of a carrier (in itself a rather conspicuous event), the monitoring of unscheduled or unannounced launching operations

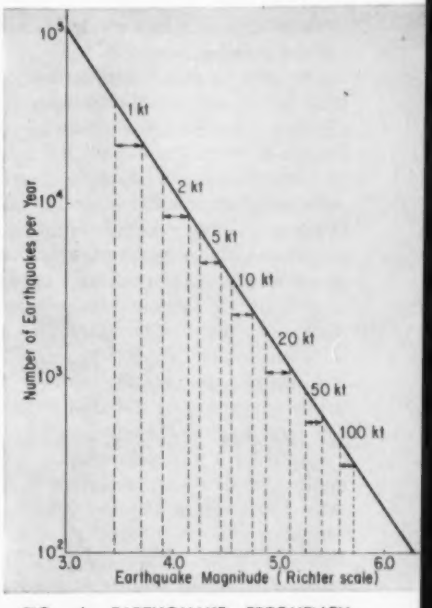


FIG. 4. EARTHQUAKE FREQUENCY. Plot of number of earthquakes per year vs. size shows large numbers of signals from quakes would have same magnitude as seismic signals from nuclear tests

of this type might relieve the evidently difficult problem of monitoring for explosions at large distances from the earth.

SIGNAL DETECTION

We have already made some scattered references to aspects of the overall detection problem. Broadly speaking, the limits do not appear to be the capabilities of the instruments now available. The limits appear to be set by the need for the instrument to be close enough to the event so that the signal overrides uncontrollable natural fluctuations in the physical quantity that the instrument monitors. There is bound to be further development in the means for distinguishing between

signals from various types of sources; such developments, however, will not change the nature of the problem or remove it completely, but merely increase the range at which a signal may be identified, or decrease the size of the signal (or explosion) that may be identified at a given range. Admitting that improvements must be possible, we shall now consider the situation in the light of present discrimination techniques for each of the signal types.

Radioactive debris. The background is essentially nil in the atmosphere, at least after radioactive debris already in the atmosphere decays and diffuses for some time.

The collection of adequate samples from one kiloton exploded in the troposphere is usually possible at ranges of thousands of miles, but is not completely certain. For example, if some meteorological condition causes the cloud to stay fairly localized and then to rain out, the radioactivity would be apparent only in a restricted area which need not include a ground air-collection station or a flight pattern for air-borne sampling equipment.

Although, at present, radioactive debris appears to be the most distinctive (and possibly the only conclusive) evidence for a nuclear explosion, as a method of detection it suffers in all cases except those of underground or near-surface burst from a lack of precision as to the original scene of the explosion. At the moment this is done through meteorological backtracking of the trajectory of the air mass after the date of the explosion has been determined by comparing the relative activities of various fission products. (The time would be obtained to within 5–10% of the age of the debris if the sample contains the products of about 10^{10} fissions.)

Air-acoustic. We have already indicated the sort of variability to be expected in the strength of the signals from explosions in the lower atmosphere. There is, of course, always a background noise level registered on an installation of microbarographs, even with an array of such instruments and strenuous attempts (e.g., long pipes with manifolded inlets) to cancel out purely local effects. The problem of reading, say, a signal of 0.5–1 dyne/cm^2 is mainly one of the noise level of the atmosphere over the array at the time. Much can be done by choosing suitable terrain (flat and covered with trees or shrubs); but while such a station may often be able to pick up a signal of a few tenths dyne/cm^2, a windstorm can put it out of action for signals of less than about 100 dynes/cm^2.

When the upper winds are mainly in one direction, an explosion of one kt (between the surface and 50 km altitude) can be detected with a high (75–90%) degree of confidence downwind at 2,000–3,000 km, upwind to 500 km, and in other directions (or all directions, with the upper winds variable) at about 1,300 km. The event can be located with an accuracy of better than 100 km in radius using the records from three stations.

Hydro-acoustic. The problem here is one of positive identification rather than detection. Several hydrophones in the submarine sound channel tied in to a coastal or island station should detect a 1 kt explosion in the oceans at 10,000 km.

Seismic. The background noise for seismic observations is quite decisive. The important things are to register the direction of first motion in as small a signal as possible, and, using an extended array of instruments, to obtain a bearing on the source. In addition to the large-scale natural disturbances of Fig. 4, there is the microseismic noise. This varies from place to place and time to time (being larger in winter than in summer) and sets a limit on the magnitude of the signal that can be observed. These disturbances, which are continually registered on sensitive seismographs, are caused by distant freight trains, industrial activities, local winds and so forth—but above all by storms at sea.

The quietest regions for seismic recording are generally found in mid-continental sites. The seismic noise conditions are much less favorable near coasts or on island locations or in areas where natural seismic disturbances are common. The Conference of Experts generally agreed that a noise background of one millimicron was available only at good stations on quiet days, three millimicrons was a more normal situation, and ten millimicrons was typical in coastal areas. A panel of seismologists, reviewing the observations made in the fall of 1958 for the underground tests conducted in Nevada, concluded that a signal-to-noise ratio of about 3 to 1 would be necessary to make effective use of the criterion of the direction of first motion. This is a more exacting requirement than that assumed during the discussions at Geneva. Apparently detection is more difficult than had been assumed at that conference; either more stations will be required to accomplish the same objectives, or the stated number of stations will be limited to detecting underground explosions of a larger yield than assumed. The effect of background noise on the range of detection (or of any stated requirement on signal-to-noise ratio) can be estimated from Fig. 3.

Most natural seismic disturbances originate in rather restricted areas, and it is against these natural signals that one must plan to discriminate. For this reason a higher density of detection stations has been proposed in the regions which have a naturally high seismic-noise background.

Little is known about the possibilities of suppressing the seismic wave resulting from an underground explosion. Perhaps a special shape of the cavity, tamping with "sound proofing" materials, canny choice of environment or a very large natural or man-made underground chamber might cause the emergent signal to be suppressed or altered; however, the scale of effort required to make an effective change in the signal from some kilotons of energy release is likely to be quite large—i.e., thousands of tons of material or many thousand cubic meters of volume.

Electromagnetic. Here there are two situations to consider: explosions in or near the atmosphere (possibly up to 1,000 km altitude), and explosions further out. The first situation should yield vertically polarized signals which might be picked up by vertical or loop-shaped direction-finder antennae. These would be dispersed a few km from each other and would be capable of detecting signals as small as a few mv/m at frequencies of one to a few hundred kc. An explosion of about one kt in the lower or middle atmosphere should be detectable at 6,000 km or more and the azimuth of the source determined to about 2°.

At higher altitudes the signal should be somewhat different, depending more on the change in the ionosphere caused by the X-rays impinging on the upper atmosphere. Although the effect is certain, the type of signal that results is not well known.

The big question for electromagnetic signals is also one of natural back-

ground. Thunderstorms can completely swamp the detection capability of a near-by station. To minimize background the site should be in rather flat terrain, far from sources of electrical interference. For the very-high-altitude situation the question of background fluctuation needs further study.

Visible light. Visible light signals, unavailable for contained explosions and of quite limited range for explosions in the atmosphere, begin to be of value for explosions high in the atmosphere. At these altitudes the X-ray radiation is absorbed and the energy re-emitted as fluorescence from the atomic and molecular excitation of the air. Even when the degree of ionization is quite low compared with the ionization caused by irradiation from the sun, some of the spectral effects are probably sufficiently accentuated to provide a distinctive signal to monochromators. This possibility requires further study and, in addition, one can imagine suppressing the effects with shielding materials close to the device on the side toward the earth.

Very high altitude. At very high altitudes, apart from the effect of X-rays on the ionosphere, detection depends on detecting the direct radiations themselves. These are neutrons, prompt gammas, delayed gammas, X-rays and visible quanta. At very high altitude (in vacuo) the visible light is not likely to be important. At very long range the velocity spread of the neutrons will spread the signal out in time to an extent that will probably make it useless. This leaves the prompt gammas (which can be shielded with a sufficient investment in mass—i.e., several times the mass of the device proper), the delayed gammas (which only appear over appreciable periods of time and hence give reduced signals per unit time), and the X-rays, whose effects may also be mitigated or suppressed by an able and determined violator.

One can, of course, go on to construct hypothetical detection systems with satellites carrying X-ray and gamma-counters operated with coincidence circuits (and anticoincidence circuits to guard against spurious signals due to cosmic-ray showers formed in the material of the satellite, X-rays from solar flares, and so on) that might be capable of detecting explosions of various sizes out to radii of the order of the radius of the solar system. There is evidently no end to such hypothecations, nor any imminence to the appearance of such a detection system.

There is, finally, the point that testing at very high altitudes, though feasible, is difficult. Nations, such as the U. K., U. S. and USSR, which already have highly destructive weapons in hand, *could* mount such an undertaking; but would certainly have to weigh the resultant advantages in weapon characteristics against the cost and the chance of being caught out. Real newcomers to the field are unlikely to be able to make much use of such uncalibrated observations, or to complicate their first experiments with the difficulties of obtaining significant data under such conditions.

Appendix—Pressure Waves in Air

Although the propagation of the pressure wave in air would appear at first sight to be one of the simpler consequences of an explosion, it is not particularly simple; hence, a brief discussion of some of the factors affecting its generation and propagation would seem worthwhile.

First, there is the very early phase (out to a few meters) in which the transport of energy is mainly governed by the flow of radiation. This is followed by a phase in which there is a strong hydrodynamic shock (heating the air to quite high temperatures). Further out, the signal becomes acoustic (or semi-acoustic), and it is far out in this phase that we are interested—since at closer ranges one could scarcely fail to notice the event.

The signal in air (or water, or rock) has a sharp pulse of increased pressure followed by a rarefaction, and the separation in time and distance between the first positive pulse and the following negative pulse increases progressively as the signal proceeds. The energy in the wave is not constant but decreases with distance because the sharp shock front heats the air, and energy is dissipated irreversibly in this heating.

At large distances (hundreds to thousands of km), where the material velocity is small compared to sound velocity in the medium, the peak pressure (more properly, over-pressure) in the wave propagated in a homogeneous three-dimensional medium would be expected, in an asymptotic approximation, to vary as

$$p \sim \frac{\text{constant}}{R\,(\ln R)^{1/2}} \qquad (1)$$

where p is the over-pressure, and R the distance from the source. The constant in the expression above is essentially proportional to the cube root of the energy release, once the properties of the homogeneous median are assigned; but the coefficients in the proportionality depend on the thermodynamic properties (equation of state) of the medium. The derivation of this relation, and its limitations, are discussed in detail by H. A. Bethe in Chap. 20 of AECD-2860, "Shock Hydrodynamics and Blast Waves."

However, the real medium is far from homogeneous. The air density varies with altitude, dropping by a factor of e about every 25×10^3 ft. The temperature and the sound velocity (which is proportional to the square root of the temperature) vary with altitude in a complicated way. The velocity goes through a minimum at 75,000 ft and again at 225,000 ft. By analogy with familiar laws of optics, this means that the signals will tend to channel into these two zones as they propagate. (The phenomenon of "sound channels" is also present for acoustic signals in the ocean and for electromagnetic signals in the atmosphere.)

A simple model, proposed by H. A. Bethe, is evidently more relevant for discussing the propagation of a wave in such a medium than Eq. 1, which refers only to a homogeneous medium. We assume that the energy in the wave is distributed through the volume $V = 2\pi R^2 \alpha h$, where h is the height of the sound channel, R is the radial distance of the wave from the source and α gives the radial thickness of the wave in terms of R. This thickness αR is the distance the signal spreads because of the variation in sound velocity (10–15% in the case of air) between different parts of the sound channel.

The energy per unit volume (ϵ) will be half kinetic and half potential, so that, if u is the material velocity

$$\epsilon \simeq \rho u^2 \qquad \text{or} \qquad \epsilon \simeq \rho \frac{u_1^2}{2}$$

if u_1 is the maximum material velocity, since the mean square velocity will be $\frac{1}{2}u_1^2$. By conservation of momentum, the peak pressure p_1, equals Mu_1, where M is the mass of air affected per unit area per unit time; for a weak shock, M is ρc (with c as the sound velocity) and

$$\epsilon \simeq \frac{p_1^2}{2\rho c^2}$$

Thus, if W is the total energy appearing in this mode, and since $\epsilon \sim W/V$

$$p_1 \sim \left(2\,\rho c^2 \frac{W}{V}\right)^{1/2} = \left(\frac{\rho c^2}{\pi \alpha h}\,W\right)^{1/2} R^{-1}$$

What emerges from this is that in two dimensions, with dispersion, the pressure goes as R^{-1} (just as in three dimensions without dispersion) and, second, that the pressure goes as the square root, rather than the cube root, of the energy (or a quantity related to the energy).

By taking more care with the constants in this proportional relation, Bethe has estimated that the pressure available at a distance of 1,000 km from a 1-kt explosion is about 10 dynes/cm² in air, 3.5×10^4 in water, and 5×10^3 (for all wavelengths) or 3×10^2 dynes/cm² (for long waves only) in rock. In doing this, he had to make some assumption about the fraction of the total energy that shows up in the acoustic signal; this has been observed to be about $\frac{1}{3}$ for air, and is assumed to be larger (60%) for rock and water.

Effect of Alpha-Beta Thermal Cycling on Uranium and Its Alloys

New uranium alloys or fuel-slug designs are needed to permit the use of metallic fuel at high temperatures. Materials of >90% U submitted to thermal cycling through the α–β transition temperature (660° C) show dimensional instability

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A MAJOR PROBLEM confronting reactor engineers is the peak temperature for uranium-metal fuel elements. If this temperature could be raised, the cost of power and/or plutonium would decrease. For instance, if the peak fuel-element temperature could be raised from 650° to 800° C, the cost of power would decrease markedly for the sodium-cooled graphite-moderated reactor.

Approximately 660° C (the α–β phase transformation) is the present temperature limit for uranium-rich fuel elements. This is caused particularly by the abrupt ~1.5% change in density accompanying the transformation. Actually, other factors, which are not discussed here, are also involved in fuel-element stability: clustering, orientation, segregation of impurities and strength vs. temperature.

Thermal Cycling

To evaluate this problem, uranium and uranium-alloy slugs were thermal-cycled through various elevated temperatures. Two types of tests were made: (a) fast cycling by rapid quenching and (b) slow cycling in a furnace.

It should be emphasized that radiation distortion and thermal-cycling distortion are distinct problems in power reactors using solid-metal fuels. Thermal cycling in the laboratory is not a tool for estimating radiation damage but rather a way of simulating actual thermal excursions anticipated during reactor operation. It is somewhat limited in that the stresses due to the thermal gradients in slugs in a reactor would be consistent in direction while the direction of the stresses under cycling would reverse with each half-cycle. The effects of axial gradients are also omitted in these tests. However, it is believed these tests give some indication of what the fuel does as it cycles in and out of the beta phase. Only reactor evaluation of uranium fuel materials can confirm the value of the thermal tests.*

Both rapid and slow thermal cycling into the β-phase of α-rolled and powder-compacted uranium cause large dimensional changes in rod-shaped material. The distortion appears to be due to the α–β phase change and not to the temperature level.

For rapidly cycled rod-shaped specimens with large temperature gradients, the deformation takes the form of large internal voids and large increases in length. Specimens of similar materials with lengths equaling diameters were cycled by the same method. They developed large internal voids but changed in length only within the limit of accuracy of the test. β-quenched rods under ½-in. diameter did not develop internal voids.

Unalloyed uranium, both α-rolled and powder-compacted, when slow-cycled between the α-phase and β-phase with small temperature increments, had

* Alloys selected partly on the basis of thermal-cycling results have been irradiated in the SRE and are now undergoing preliminary examination.

TABLE 1—Results of Rapid-Quench Thermal Cycling

Test	*Material*	*Specimen size (in.)*	*Δl (%)*	*Δd (%)*	*Internal void*	*End effect*
50 quenches, 680°–20° C	α-rolled	1¼ × 4	+11	−1	large, continuous	dog-boned, cupped
	α-rolled	¾ × 4	+16	−9	large, continuous	dog-boned, cupped
	powder-compacted	¾ × 4	+20	−16	large, discontinuous	dog-boned, cupped
	α-rolled	¼ × 4	+12	−23	none	slightly dog-boned
	α-rolled			−3	large,	spool-shaped
		1 × 1	+4	+3	continuous	
	powder-compacted	¾ × ¾	+1	+2 −7	large, continuous	spool-shaped
50 quenches, 630°–20° C	α-rolled	1 × 4	+2	−2	none	very slight
	powder-compacted	¾ × 4	+2	−1	none	very slight

NOTE: All specimens were held at temperature in the salt bath for 15 min before quenching. Weight losses due to scaling and corrosion on all of these specimens were high (10–20%).

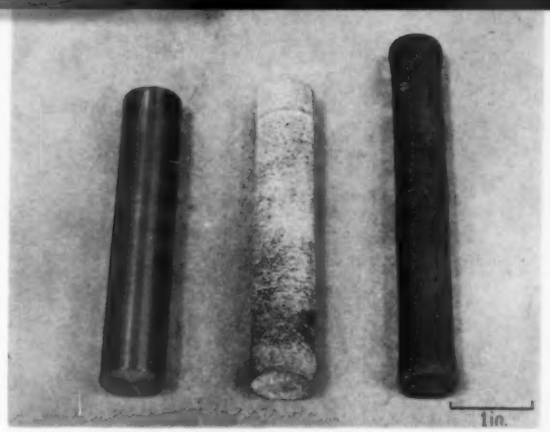


FIG. 1. UNCYCLED SLUG AND α- AND β-QUENCHED SLUGS after 50 thermal cycles. β-quenched slug shows greater elongation and dog-boned ends

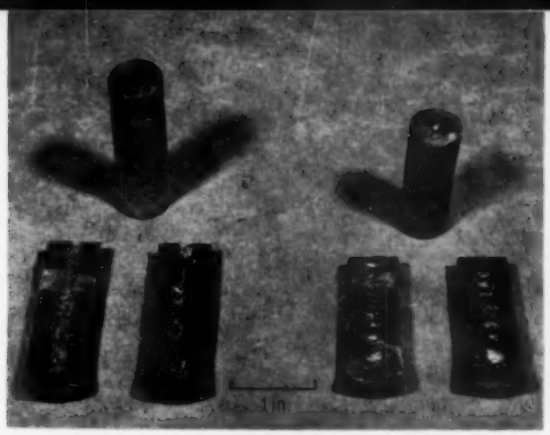


FIG. 2. BETA-QUENCHED SLUGS, after 50 quenches, developed large internal voids as well as dog-boned ends. Void formation is accounted for by difference in density of α and β phases

severe surface ruptures, large length decreases and correspondingly large diameter increases. The same materials cycled with small temperature increments within the high α-phase or the low β-phase showed relatively small dimensional changes. An increase in the α–β cycling temperature increment also produced gross distortion.

Some powder-compacted uranium alloys were relatively stable to the slow α–β cycling. Cold-pressed and sintered alloys were appreciably more stable than alloys of the same composition that were hot-pressed. The unstable hot-pressed alloys included those using aluminum, bismuth, niobium, silicon and tin, while the stable cold-pressed and sintered alloys included those of chromium, molybdenum, niobium, silicon and zirconium.

It appears that considerably more experimental effort is required before a uranium-metal-fueled reactor can be operated with a peak slug temperature exceeding 650° C for extended periods.

The dimensional changes occurring from relatively slow α–β temperature excursions can probably be contained by 60–100 mils of strong, low-temperature case material. A few minor temperature excursions into the β-phase would probably be permissible under reactor conditions. For sustained higher-temperature operation, new designs and materials appear to be necessary.

Some modifications in design and materials that could be adopted to minimize these dimensional-stability problems are (a) a hollow slug that permits relief of internal stresses, (b) thorium-uranium fuel slugs that have no low-temperature phase change, (c) uranium alloys that are more stable and (d) elimination of undesirable phase changes by greater alloying additions to the uranium.

Rapid-Quench Cycling

The fast cycling was accomplished by transferring slugs from a heated salt bath to a water quench. This test simulates the extreme temperature gradients encountered during reactor scram, 400°–600° C. Two carbonate-salt-bath temperatures were used: 630° C (α-quench), and 680° C (β-quench).* The materials tested were α-rolled uranium and powder-compacted uranium of various sizes and shapes.

The initial series of rapid thermal cycles consisted in quenching α-rolled uranium and powder-compacted uranium rods both from the high α-phase (630° C) and from the β-phase (680° C). In all tests, the specimens were held in the salt bath for 15 min and immediately quenched in cool water. Fifty quenches were used as a standard test with measurements being made at intermediate intervals.

Table 1 gives the results of rapid α- and β-quenches, and Fig. 1 shows a comparison of the different quenches. Specimens quenched from the high α-phase elongated slightly, and there were no internal voids.

Large internal voids and dog-boned ends formed in the β-quenches, as shown in Fig. 2. The formation of internal voids appears to be reasonably explained by the difference in density between the two phases. As the slug is removed from the salt bath, it is entirely in the β-phase, and upon quenching in water an exterior shell rapidly transforms to α-material while the interior remains in the β-phase for a somewhat longer period. As this α-shell increases in thickness, with the decreasing diameter of the β-phase interior, it forms a strong rigid member. As the last material at the center transforms from a large volume to a smaller volume, it is unable to pull the stronger outer shell into the available volume—and thus a cavity results. The reason for the discontinuous cavities in the powder-compacted and the continuous cavities in the α-rolled uranium is not known. It is believed to be a function of the grain orientation, grain size, segregation of impurities and the relative anisotropy of the yield strength.

* These quenching tests are similar to work performed at Hanford [L. F. Levenick, HW-28305 (1953)].

Shape Factor

α-rolled uranium specimens of various shapes were β-quenched by the same method as used for the slugs. Rod specimens ($l > d$) varied in diameter between ¼ and 1¼ in. The ¼-in.-diameter rod grew in length less than the larger-diameter rods and contained no internal voids but warped appreciably. A ½-in.-diameter rod and all larger-diameter rods grew in length, had dog-boned ends and contained internal voids. The data for all the rod tests showed a linear relationship between growth and the number of cycles.

In a second series of shape-factor tests, cylinders and spheres of α-rolled and powder-compacted uranium were β-quenched. None of these specimens showed a tendency to elongate appreciably in a preferred direction. The cylindrically shaped specimens developed very large internal voids and became spool-shaped, while the sphere shortened slightly along the rolling axis and developed a very large internal void.

Continued on next page

TABLE 2—Results of Slow Thermal Cycling

Test	*Material*	*Specimen size (in.)*	Δl(%)	Δd(%)	*Surface after test*
200 cycles, 580°–630° C	α-rolled	⅝ × 3	+ 0.7	− 0.4	smooth
	α-rolled	⅝ × 3	+ 0.6	− 0.3	smooth
200 cycles, 630°–680° C	α-rolled	⅝ × 3	− 3.3	+ 5.1	rough
	powder-compacted α-rolled	⅝ × 3	+ 1.1	+ 4.8	rough
	α-rolled	⅝ × 3	−25.0	+ 9.8 (varies)	severe surface cracking
	α-rolled	⅝ × 3	−31.0	+19	
200 cycles, 680°–730° C	α-rolled	⅝ × 3	− 1.4	+ 0.8	very slight roughness
	α-rolled	⅝ × 3	− 2.6	+ 2.4	smooth

NOTE: Each cycle was 15 min total time.

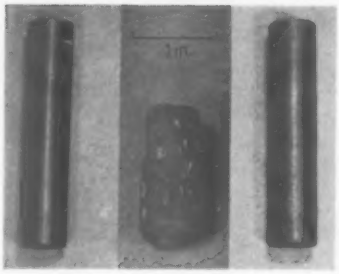


FIG. 3. SLOW FURNACE-CYCLED SLUGS, cycled (from left to right) below, bracketing and above α–β phase-transformation temperature. Dimensional changes are, respectively, $\Delta l = +0.7\%$, $\Delta d = -0.4\%$; $\Delta l = -31\%$, $\Delta d = +19\%$; $\Delta l = -2.6\%$, $\Delta d = +2.4\%$

Slow Furnace Cycling

The thermal-cycling tests consisted in cycling uranium and uranium-alloy specimens at temperatures above, below and bracketing the α–β phase-transformation temperature. The temperature changes in these tests (25°–50° C) were appreciably smaller than in the quench tests. The specimens were slugs 1–3 in. long by ½–¾-in. diameter sealed in evacuated Vycor tubes and placed in a low-heat-capacity resistance furnace operated by a program controller.

The following tests were made:

1. 580°–630° C at 15 min/cycle in the high α-phase
2. 630°–680° C at 15 min/cycle, bracketing the α–β transformation
3. 680°–730° C at 15 min/cycle, in the β-phase
4. 200°–700° C, at 1 hr/cycle, from α to β and back
5. 630°–680° C with the specimens jacketed in stainless steel of varying wall thickness to observe the strength required to restrain the dimensional changes.

Although the temperature conditions in these slow-cycling tests do not represent those to be encountered in reactor operation, the tests do indicate the relative stability of different uranium materials.

The results of using cycles 1, 2 and 3 are given in Table 2 and Fig. 3. With α-rolled uranium, α-phase cycling generally increases the length and decreases the diameter of rod-shaped sections. Cycling in the β-phase results in slightly more distortion, with the direction of the dimensional changes being exactly the reverse of the α-phase-cycling distortion. The α-to-β-cycled rod was severely distorted by shortening in length up to 30%, increasing in diameter by about 20% and rupturing all surfaces.

Effect of Alloying

Dilute uranium alloys were thermally cycled through the α–β phase change (cycle 2) with the results shown in Table 3 and Figs. 4 and 5.

The alloys were all fabricated by powder metallurgy techniques by Sylvania Electric Products, using hot-pressing or cold-pressing plus sintering.

There was a large difference in the dimensional distortion, depending on the method of fabrication of some alloys. The cold-pressed and sintered alloys were generally much more stable than the hot-pressed alloys. This phenomenon is probably due to the more rapid and complete alloy formation at the sintering temperature (1,000–1,120° C) than at the hot-pressing temperature (~600° C). The dimensionally unstable hot-pressed alloys contained aluminum, bismuth, niobium and tin. The relatively stable hot-

FIG. 4. COLD-PRESSED AND SINTERED U ALLOYS. Metallurgical structure before and after α–β cycling

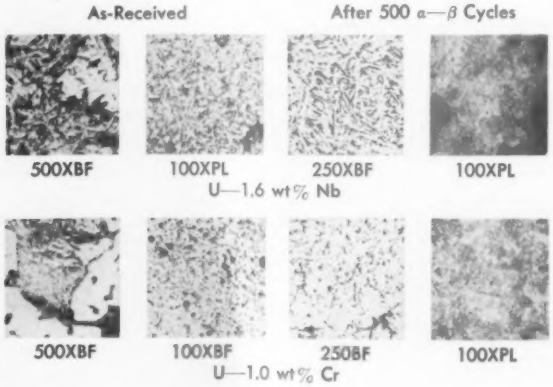
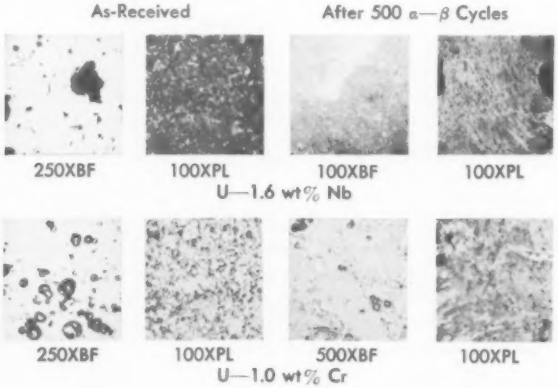


FIG. 5. HOT-PRESSED U ALLOYS. Metallurgical structure before and after α–β cycling



pressed alloys contained chromium, molybdenum and silicon. The latter alloys, together with the zirconium alloy, were even more stable when cold-pressed and sintered.

All of these alloy specimens were also cycled at lower temperatures (100°–500° C) and showed good dimensional stability. It was the higher temperature cycling that separated the stable and unstable specimens. The stabilizing effect of the alloys for high-temperature cycling appears to be generally due to (a) increased strength at elevated temperature, (b) inhibition of grain growth, (c) change in the phase-transformation temperature and (d) suppression of the phase-transformation rate.

The relationship of dimensional stability to metallurgical structure in these alloys is not completely understood and will require further study. It remains to be observed if the changes noted are a result of cycling, of thermal effects or a combination of both.

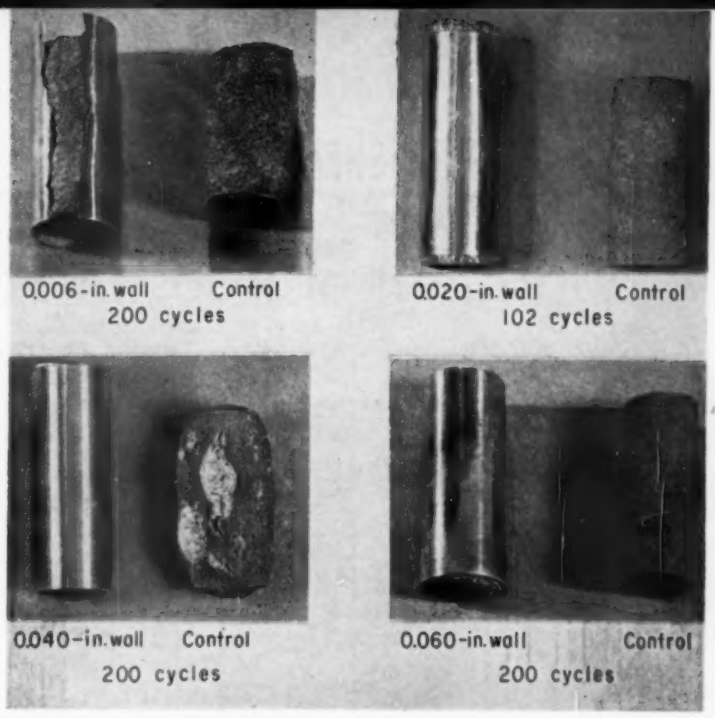


FIG. 6. JACKETED SLUGS. Uranium slugs were α–β cycled while restrained in stainless-steel jackets. Only thinnest jacket ruptured

Restrained Slugs

To estimate the strength of material required to restrain the dimensional changes that result from α–β cycling, type 321 stainless-steel jackets were shrunk onto α-rolled uranium slugs. Stainless steel at 700° C has about the same yield strength as α-uranium at 600° C; thus, the steel jacket simulates a case or shell of α-material. Steel jackets of approximately 10, 20, 40 and 60 mils were used. All of the α-rolled uranium rod specimens were $\frac{5}{8}$ in. by 2 in. The ends of the jackets were machined flush with the uranium; thus the ends of the slugs remained unrestrained.

The experiment consisted in cycling the specimens 200 times (or until failure) through the α-β transformation temperature (cycle 2). Each test included an unjacketed control specimen and one or two jacketed specimens. The reason for the variation in the distortion of the control samples is not known.

The 0.006-in.-wall specimens ruptured in less than 100 cycles. The 0.020-in.-wall specimens grew more out of round as the number of cycles increased, with severe distortion after 400 cycles. The 0.040-in.-wall specimens had a minor increase in diameter (0.005 in. max) after 100 cycles and only a slight further increase (0.001 in. max) between 100 and 400 cycles. After 100 cycles, the 0.060-in.-wall specimens had a maximum increase in diameter of 0.003 in. This diameter increased insignificantly after 300 additional cycles. There were no jacket failures in either the 0.040-in.- or 0.060-in.-wall specimens. Results of typical tests are shown in Fig. 6.

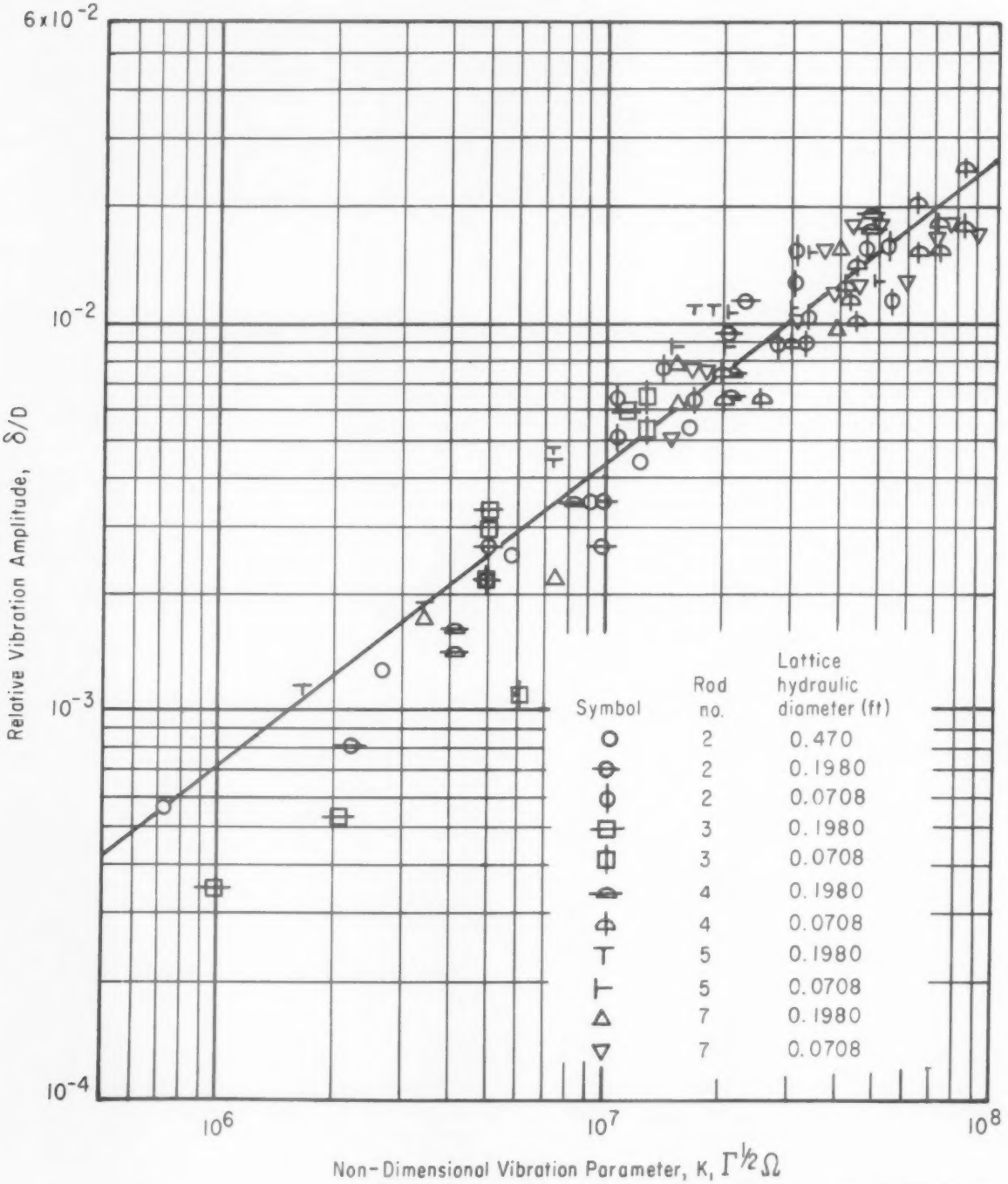
TABLE 3—Results of α–β Thermal Cycling of Powder-Compacted U Alloys

Alloy (*wt %*)	Δl (%)	Δd (%)	*Surface, after*	*Internal structure*	*Original grain size* (μ)	*Est. final grain size* (μ)	*Original hardness* (*DPH*)	*Final hardness* (*DPH*)
Hot-Pressed Alloys								
U-1.6 Nb	+65	+27	bumpy, porous	very porous	4–17	80	278	238
U-1.0 Cr	−9†	+8*	slightly rough	solid	8–17	75	283	365
U-1.0 Bi	+16	+17	badly cracked	very porous	4–17	120	273	257
U-2.0 Sn	+8	+36	badly cracked	very porous	12–18	120	245*	307*
U-1.0 Al	−13	+23	badly cracked	slightly porous	8–17	60	288	249
U-0.5 Si	+3	+5	slightly rough	solid	8–17	70	297	347
U-0.4 Mo	+7	+9	slightly rough	slightly porous	8–17	20–80	272	278
Cold-Pressed and Sintered Alloys								
U-1.6 Nb	+4	+0.5	slightly rough	solid	38–50	80	435	308
U-1.0 Cr	+1	+2	slightly rough	solid	50–300	75	317	378
U-0.4 Si	+5	+4	slightly rough	solid	50–400	30–80	373	259
U-1.2 Mo	+0.6	+1.2	smooth	solid	38–70	50	329	323
U-7.0 Zr	+2	+3	rough	solid	4–60	65	329	274

* Some wide variations.

Vibration of Rods in Parallel Flow

DAVID BURGREEN, *Nuclear Development Corp. of America, White Plains, New York*



A COMMON TYPE of reactor core configuration consists of fuel rods uniformly clustered together, with a coolant flowing parallel to the axes of the rods. To keep the friction losses in the core as low as possible the number of fuel-rod supports should be a minimum. But if the rods have long unsupported spans, they are susceptible to vibrations; under certain conditions the vibrations may become large enough in amplitude to damage the rods.

The figure summarizes the results of an experimental program to determine the nature and magnitude of vibration of clustered rods in parallel flow. The rods vibrate at approximately their fundamental (damped) frequency of vibration at all velocities of flow. An analytical-dimensional analysis of the system (*1*) indicates that the amplitude of vibration is influenced by the physical constants listed in the column at the left side below. The column on the right indicates the range of the constants covered in the experimental program.

Physical Variable	*Range of Values in Tests*
D Lattice hydraulic diam	0.078–0.470 ft
V Flow velocity	6–21 fps
ρ_w Fluid density	62 lb/ft³*
μ Fluid viscosity	2.0 lb/ft-hr*
ρ_r Rod density	0.1–0.31 lb/ft³
I Rod moment of inertia	0.00245–0.00735 in⁴
E Rod modulus of elasticity	10×10^6 and 12×10^6 psi
k_1 End-fixity factor	5.0–2.92
L Rod length	4 ft*
A Rod cross section	0.304 in² (⅝ in. diam)*

The column on the right shows that the effects of varying six of the ten pertinent physical variables are contained in the tests. The test results are plotted in terms of the non-dimensional parameter $k_1\Gamma^{1/2}\Omega$. k_1 is related to the end-fixity (*2*) of the rod and is determined from the expression for the maximum deflection of a beam with a uniform load w

$$y_{max} = \frac{k_1}{384}\frac{wL^4}{EI}$$

When the rod is pin-ended, k_1 would be 5; when the ends of the rod are rigidly held k_1 would be 1; and, when one end of the rod is pin-ended and the other end rigidly held, k_1 would be 2.08. The non-dimensional parameter Γ is the ratio of the hydrodynamic force of the water to the elastic restoring force of the rod

$$\Gamma = \frac{\rho_w V^2 L^4}{gEI}$$

and the non-dimensional parameter Ω is the ratio of the hydrodynamic force of the water to the damping force on the rod

$$\Omega = \frac{\rho_w V^2}{\mu\omega}$$

In addition to the symbols in the table, we define ω = actual damped fundamental frequency of vibration (circular) in fluid—proportional to $(gEI/\rho_r AL^4)^{1/2}$—and δ = amplitude of vibration.

A curve that approximates the test results fairly well is given by the expression

$$\left(\frac{\delta}{D}\right)^{1.3} = 0.83 \times 10^{-10} k_1\Gamma^{1/2}\Omega$$

which is the straight line in the figure. Either the above expression or the curve in the figure may be used by the designer to estimate the spacing of the rod supports.

Example

Solid aluminum rods 4 ft long and ⅝ in. in diam are arranged in a triangular lattice with a pitch spacing of 0.914 in. If the ends of the rod are fitted with ball-and-socket-type joints, what is the maximum amplitude of vibration to be expected when water at room temperature flows parallel to the rods at a velocity of 20 fps? If the rods were 7 ft long and the velocity of flow 30 fps, would adjacent rods strike each other?

The constants are $V = 20$ ft/sec; $E = 10^7$ psi; $I = \frac{\pi(0.625)^4}{64} = 0.0074$ in⁴; $\rho_r = 0.1$ lb/in³; $D = 0.0708$ ft $= 0.85$ in. These numbers together with the values shown in the table for ρ_w, L, μ and A give

$$f = \frac{\omega}{2\pi} = \frac{\pi}{2}\left(\frac{gEI}{\rho_r AL^4}\right)^{1/2} = \frac{3.14}{2}$$

$$\left(\frac{32 \times 12 \times 10^7 \times 7.4 \times 10^{-3}}{0.1 \times 0.304 \times 5.3 \times 10^6}\right)^{1/2} = 20.8 \text{ cps}$$

$$\omega = 2\pi f = 6.28 \times 20.8 = 131 \text{ rad/sec}$$

Assume 20% frequency reduction because of viscous damping in water:

$$\omega(\text{damped}) = 131 \times 0.8 = 105 \text{ rad/sec}$$

$$\Gamma^{1/2} = \left(\frac{\rho_w V^2 L^4}{gEI}\right)^{1/2} = \left(\frac{0.0358 \times 5.76 \times 10^4 \times 5.3 \times 10^6}{32 \times 12 \times 10^7 \times 7.4 \times 10^{-3}}\right)^{1/2} = 19.65$$

$$\Omega = \frac{\rho_w V^2}{\mu\omega} = \frac{0.0358}{0.462 \times 10^{-4}} \times \frac{5.76 \times 10^4}{105} = 4.25 \times 10^5$$

Because the rod is pin-ended $k_1 = 5$. Finally we have

$$k_1\Gamma^{1/2}\Omega = 5 \times 19.56 \times 4.25 \times 10^5 = 0.417 \times 10^6$$

From the figure

$$\frac{\delta}{D} = 0.013$$

or from the proposed expression

$$\left(\frac{\delta}{D}\right)^{1.3} = 0.83 \times 10^{-10} k_1\Gamma^{1/2}\Omega = 0.83 \times 10^{-10} \times 0.417 \times 10^6$$

yielding

$$\frac{\delta}{D} = (0.00347)^{0.768} = 0.013$$

The amplitude of vibration is

$$\delta = 0.013 \times 0.85 = 0.011 \text{ in.}$$

If the rods were 7 ft long and the velocity 30 fps then the amplitude of vibration would be

$$\delta = 0.011 \times \left(\frac{7}{4}\right)^{\frac{4}{1.3}}\left(\frac{30}{20}\right)^{\frac{3}{1.3}} = 0.156 \text{ in.}$$

The clear space between rods is $0.914 - 0.625 = 0.289$ in. Two adjacent rods each vibrating with an amplitude of 0.156 in. would therefore strike each other.

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* Value constant during test.

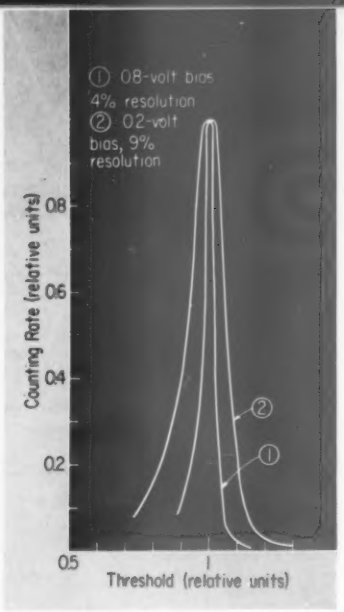

FIG. 1. ENERGY SPECTRA obtained for Po^{210} alphas with two different bias voltages across semiconductor junction

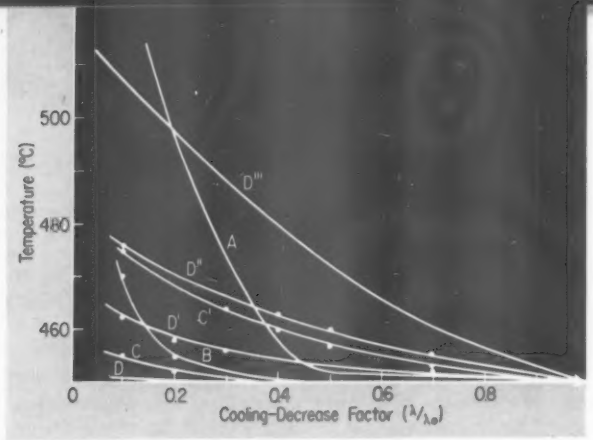

FIG. 2. FUEL-TEMPERATURE VARIATION as function of scram-rod insertion. Curves are for rod insertions of (A) 1% in 0 sec; (B) 3% in 0 sec; (C) 6% in 0 sec; (D) 9% in 0 sec; (C') 6% in 1 sec; (D') 9% in 1 sec; (D'') 9% in 0.2 sec, 0.2 sec after accident; (D''') 9% in 0.5 sec, 0.5 sec after accident

Review of French Progress in Nuclear Instrumentation

M. SURDIN, *Centre d'Etudes Nucleaires de Saclay, France*

Although short reports on French nuclear instrumentation have appeared in the American literature (1–5), NUCLEONICS feels that American scientists and engineers are not sufficiently aware of the worthwhile work performed in France. Therefore, M. Surdin, head of the electronics department at Saclay, was invited to review French progress in this field periodically. This article, the first of the reviews, includes radiation detectors, heavy-water-leak detectors, plutonium monitors, systems for fast coding, and reactor-coolant-system simulators.

THIS REVIEW of French nuclear instrumentation describes some typical recent developments. It is based in part on French contributions to the first International Symposium on Nuclear Electronics, organized by the French Société des Radioélectriciens and held in Paris in Sept., 1958 (*6*). The names of those most closely associated with the work are given at the end of each section.

Semiconductor Detectors

Experiments were conducted to study the detection of ionizing particles by semiconductors, in particular the proportional counting of α particles. The crystal used was a diffused *np* junction of germanium. A Po^{210} source provided 5.3-Mev α particles. In the avalanche region, a charge-multiplication factor of 30 was obtained. The maximum gain is limited by the variation of the dynamic resistance of the junction, which can vary from 10^7 to 10^8 ohms, as much as by the background noise.

Figure 1 gives the energy spectra obtained for Po^{210} α particles for two different biasing voltages. The resolution improves when the biasing voltage increases. In the best case, a resolution of 4% at 5 Mev was obtained.

Some encouraging results were obtained in the detection of thermal neutrons from a reactor. A silicon diffused *np* junction doped with boron was used. The junction was biased so as to obtain the best signal-to-noise ratio. For a flux of 5×10^6 n/cm²/sec, the counting rate was 30 cpm, which corresponds to a detection efficiency of 6×10^{-6}. This efficiency is low, but it is hoped that it can be improved by incorporating more boron in the crystal and, if possible, as a surface layer.—R. BOMAL, L. KOCH, N'GUYEN VAN DONG and C. SCHNEIDER

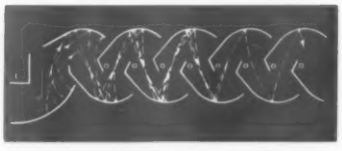

FIG. 3. ISOCHRONISM of electrons achieved by dynode design

Detecting D_2O Leaks

EL3, the materials-testing reactor at Saclay, is a 15-Mw, heavy-water-moderated and -cooled reactor. The

heat is transferred to light water in a heat exchanger.

An apparatus was designed to detect heavy-water leakage into the light water. It can detect in 30 min small leaks corresponding to a concentration of 20 ppm of heavy water in light water and, in a few seconds, an important leak, say larger than 100 ppm.

This instrument is based on the detection of a 0.51-Mev gamma line emitted by the heavy water. This γ-activity is due to fluorine-17 (β^+, half-life = 70 sec) obtained indirectly in the reactor from the $O^{16}(d,n)$ reaction. The deuterons involved in this reaction are recoil deuterons resulting from the slowing down of fast fission neutrons.

To increase the security, several γ-detectors are situated at different positions in the light-water system. Each detector is followed by its own electronic instrumentation. An arrangement allows for subtracting background activity.

When the γ-activity of light water becomes higher than a fixed level, an alarm is sounded. This alarm level is a function of reactor power. The detector circuitry is straightforward.—C. Julliot, A. Lansiart and D. Nordemann

Cooling Failure Analog

Failure of one or more cooling channels of a heterogeneous reactor can entail serious consequences. A careful assessment of power and fuel-temperature behavior subsequent to cooling failure is necessary for the design of reactor safety instrumentation. Taking into consideration the complexity and the nonlinearity of the equations involved, the most convenient way to solve this problem is to use an analog computer.

Such an analog computation was performed for EL3 under the following conditions:

1. Assuming that scram rods were not inserted after the accident: Fuel temperature and power change were plotted for the first few seconds after a sudden decrease of coolant flow. Thermal shock of fuel rods was reduced only by the temperature effect on reactivity. The fuel-temperature change was plotted for different values of the cooling-decrease factor, λ/λ_0.

2. Assuming that scram rods of different worth are inserted at various rates with a variable delay with respect to scram signal: Fuel temperature and power change were plotted during the first few seconds after a sudden decrease of coolant flow. Figure 2 gives fuel-temperature variation as a function of the decrease in coolant flow for various reactivities of scram rods, rates of injection and delay.

From inspection of these curves, it can be seen that if the coolant flow is reduced to $\frac{1}{10}$ its normal value, fuel temperature will not become higher than 500° C if in 0.2 sec 6% of negative reactivity is injected in the reactor with a delay of the order of 0.2 sec.—G. Bianchi-Courtot, J. Brasseur, C. Caillet and M. Thonnet

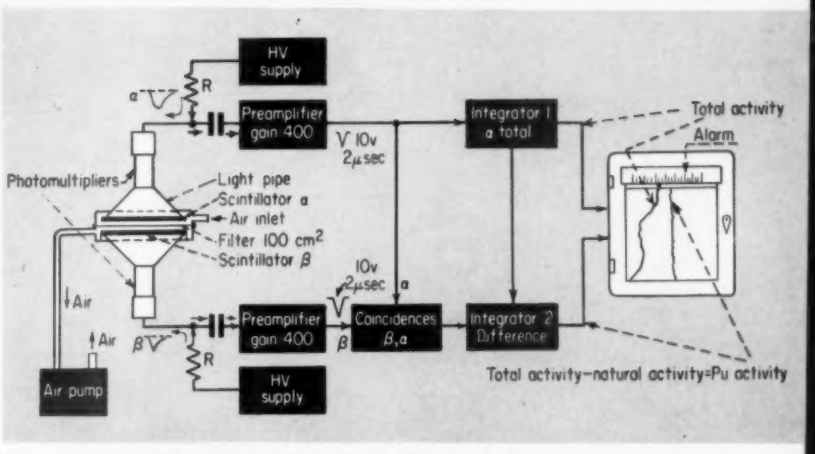

FIG. 4. COINCIDENCE SYSTEM for detecting plutonium in air

Fast Photomultipliers

The LEP type 204 photomultiplier* was designed for fast rise time, large gain ($\sim 10^8$) and large linear pulse output ($\sim$300 ma).

The fast rise time of the output pulse results from the isochronism of electron trajectories. This isochronism is obtained by means of a hemispherical photocathode (7). The dynode design provides progressive focusing of electrons and, hence, isochronism in the multiplying part of the tube (see Fig. 3).

The large gain is obtained with a tube containing 14 stages. To obtain large linear pulse currents at the tube output, the "perveance" of the last dynode-anode space is made large to avoid space-charge limitations. The time of anode-current establishment is made short to avoid effects due to displacement currents.

The response of this tube can be characterized by the following statement: For 10 photoelectrons emitted from the photocathode within 1 mμsec, the slope of the anode current at a gain of 10^9 is 200 ma/mμsec; the probable time error will be 0.07 mμsec if the electronic setup following the photomultiplier is sensitive to 2 volts and has an impedance of 100 ohms.—G. Pietri and Y. Koechlin

Scintillation Survey Meters

A scintillation surveying instrument was developed to discriminate between radiations emitted by potassium-, uranium- and thorium-containing ores. The gamma-ray energies involved are 1.47 Mev for K^{40}, 1.76 Mev for U(RaC) and 2.61 Mev for ThC.

The proportional detector is a large NaI(Tl) crystal followed by a photomultiplier. After adequate amplification, the detector output pulses are analyzed in a four-channel amplitude discriminator.

The discriminator thresholds are chosen as follows: 1st channel—35 kev, so as to obtain the total counting rate; 2nd channel—1.3 Mev, which, considering the resolution of the scintillator, permits maximum sensitivity at 1.46 Mev; 3rd channel—1.46 Mev, due to considerations similar to those for channel 2; 4th channel—2.1 Mev, since the uranium family emits few photons above 2.1 Mev.

The activities due to K, U and Th can be deduced by subtracting counting rates obtained in the appro-

* Now produced and marketed by DARIO, type 56 AVP; see Nucleonics 17, No. 6, 85 (1959).

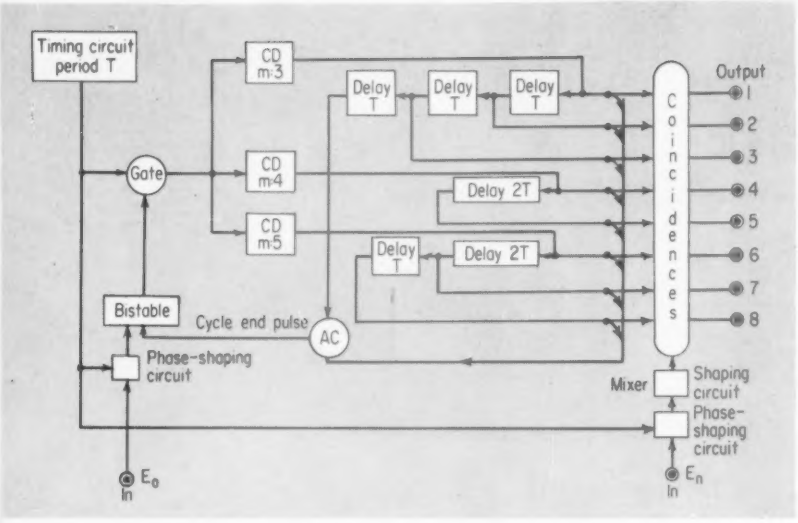

FIG. 5. FAST-CODING SYSTEM block diagram

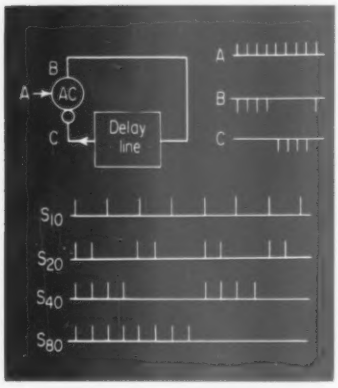

FIG. 6. FREQUENCY-DIVIDER principle and pulse chains of 4-channel system

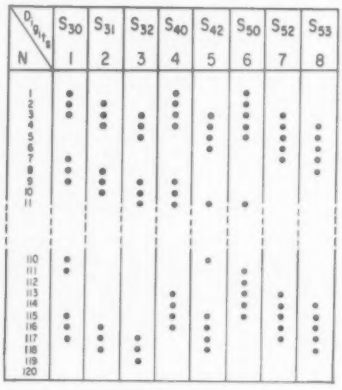

FIG. 7. PULSE TRAINS produced by system in Fig. 5

priate channels. This can be done automatically.

Preliminary results obtained with this equipment are encouraging.—J. BERBEZIER and C. LALLEMANT

Coincidence Counting of Pu

An apparatus was designed to detect the maximum permissible concentration (mpc) of Pu in air—2×10^{-12} curie per cubic meter (c/m³)—in the presence of natural α-emitters such as the daughter products of radon and thoron, whose normal activity in air is of the order of a few 10^{-10} c/m³.

Since the mpc of Pu in air corresponds to 4.44 dpm/m³, it is necessary to integrate the activity on a fixed or slowly moving filter. However, at the same time the filter collects radon and thoron daughter products naturally present in air whose activity, variable with atmospheric conditions, is a few hundred times larger than that due to the Pu mpc.

To measure α-activity due to Pu in the presence of such high background, the instrument uses the fact that the daughter products of radon form the decay chain: $\mathrm{RaC} \xrightarrow{\beta} \mathrm{RaC'} \xrightarrow[163\ \mu\mathrm{sec}]{\alpha}$. Similarly for thoron: $\mathrm{ThC} \xrightarrow{\beta} \mathrm{ThC'} \xrightarrow[0.3\ \mu\mathrm{sec}]{\alpha}$.

Alpha and beta detectors are placed on each side of the filter (see Fig. 4). Pulses from these detectors are fed into a coincidence selector having a resolution time of 300 μsec. The coincidence rate is proportional to the natural activity through the emission of β and α RaC-RaC′ and ThC-ThC′.

The instrument subtracts (taking account of detector efficiencies) the coincidence rate from the alpha counting rate, thus giving a quantity proportional to the Pu collected by the filter. An alarm can be sounded when ½ dose-day is reached.—A. BLANC and G. ROUX

Fast-Coding System

A device has been developed that gives in coded form the time interval between an initial pulse E_0 and a pulse E_n occurring at random with respect to E_0. The device (Fig. 5) can be applied to fast time-of-flight detectors and to fast amplitude selectors.

The measurement of any variable, convertible to a time interval, can be translated to arithmetic coded form. Very short intervals are accepted because of the use of delay-line frequency dividers (Fig. 6) capable of operation up to 50 Mc and fast phasing circuits.

An inspection of the waveforms delivered by the frequency dividers suggests their application to coding. Consider a group of frequency dividers whose factors of division have been chosen so that simultaneous sampling, at a given instant, of the output pulses of each of these circuits gives a combination that identifies each time interval T. Let S_p stand for a pulse train delivered by a circuit (at B in Fig. 6) whose factor of demultiplication is p; a second subscript q is added to represent the same train delayed by qT.

Figure 6 also gives pulse trains, symbolized by S_{10}, S_{20}, S_{40}, S_{80}, for a four-channel system. The digital coding of consecutive time intervals is represented by the natural binary code. Thus, with n channels, $N = 2^n$ binary positions are obtained; N is the capacity of the system.

The experimental device described here uses division by 3, 4 and 5 and $N = 120$. The different pulse trains are presented in Fig. 7. After each cycle, the system is reset.—Y. AMRAM

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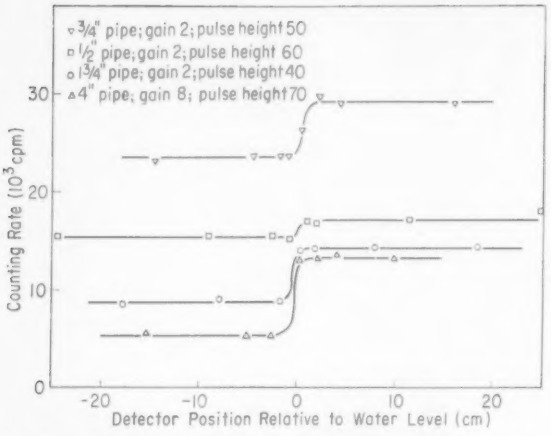
▽ 3/4" pipe; gain 2; pulse height 50
□ 1/2" pipe; gain 2; pulse height 60
○ 1 3/4" pipe; gain 2; pulse height 40
△ 4" pipe; gain 8; pulse height 70
Counting Rate (10³ cpm)
Detector Position Relative to Water Level (cm)

FIG. 1. LEVEL DETERMINATION of light water without gamma background for several pipe sizes using PoBe neutron source of 3×10^7 neutrons/sec

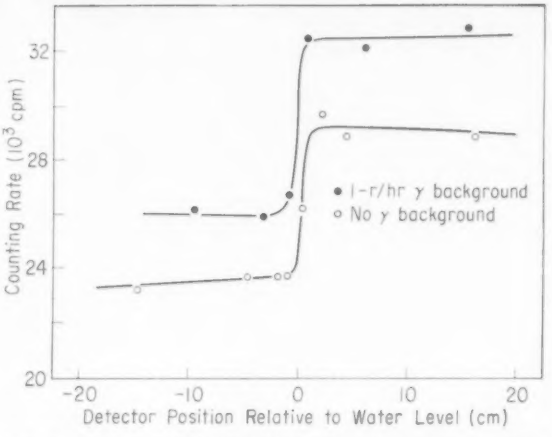

FIG. 2. LEVEL DETERMINATION of light water with and without gamma background, using PoBe neutron source of 3×10^7 neutrons/sec and 3/4-in. pipe. Gain was 2 and pulse height 50

Neutron Gage Measures Liquid Level in Intense γ-Ray Fields

T. W. MIX, D. T. MORGAN, P. N. HAUBENREICH, J. R. BOWEN, W. M. QUAM and D. C. MORSE
Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

A neutron gage has been designed and tested that can measure the water level in heavy-walled stainless-steel pipe against intense gamma-ray background, as might be necessary for a homogeneous-fueled reactor. An accuracy of ± 1 cm was attained while discriminating against a gamma field of $\sim$50 r/hr—the method should be feasible in much higher gamma fields.

The liquid-level indicator is comprised of a fast-neutron source on one side of the pipe and a fast-neutron detector on the opposite side. The assembly can be moved vertically along the pipe. A drop in the neutron counting rate indicates the presence of liquid in the pipe. Because of the high gamma background present in an operating reactor, a Hornyak button (homogeneous mixture of Lucite and ZnS powder) was used as the fast-neutron detector because of its good discrimination properties. A fast-neutron source has been used previously to measure the level of a hydrogenous liquid,* but in this previous work a slow-neutron detector was used. Slow-neutron detection would be unsatisfactory in the present application because of the presence of the shielding water.

* S. Barnartt, K. H. Sun, NUCLEONICS 13, No. 5, 47 (1955).

Experimental Tests

Four pieces of schedule-80 heavy-wall type-347 stainless-steel pipe of

The Application—Reactor Maintenance

In the ORNL homogeneous reactor, the shield tanks and all the internal equipment have been designed for flooding with water to provide a flexible and transparent shield during remote maintenance operations. Long-handled tools permit a worker to stand at ground level while tightening bolts or making adjustments on equipment inside the flooded pit.

When the system piping must be opened to remove equipment, the reactor fuel can be drained and flushed to the outer storage tanks. Next, the pipeline would be filled with heavy water that has been evaporated from fuel solution, and freezer jackets would freeze a heavy-water ice plug in the line. This ice plug would prevent the leakage of shield water into the reactor piping during disassembly. Knowledge of the heavy-water level in the vertical piping is thus needed so that the freezer jacket can be properly located on the pipe.

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* The unit $\frac{EFF^2}{B}$ (efficiency² over background) is actually the figure of merit of any counting system. A system with a higher $\frac{EFF^2}{B}$ lets you count more accurately in a shorter length of time.

Data taken to optimize figure of merit (-20° C, tritrated toluene in toluene, PPO and POPOP, differential operation).

DATA WITH *Tritium*

	TYPICAL COUNTING EFFICIENCY	FIGURE OF MERIT * $\frac{EFF^2}{B}$
B/A model 745	40%	1.75 †
double tube coincidence system	20%	1.5

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This article starts on page 84

½-, ¾-, 1¾- and 3½-in. nominal diameter and 3 ft long were used as standpipes with which the level indicator was to be tested. They were sealed at one end and held vertical. Water level was indicated by a simple manometer with a small Tygon tube inserted below the water level from the open end of the pipe. To obtain most of the data, pipes containing light water were surrounded by paraffin to simulate the shield water. Heavy water was used in the last run to simulate more closely the expected operating conditions.

The detector circuit consisted of an RCA 5819 photomultiplier; preamplifier; Radiation Counter Laboratory Model A-1, Mark 15 linear amplifier; Victoreen Model 083 regulated high-voltage power supply; and RCL Model 2006, Mark 13 scaler. In the tests, the photomultiplier voltage was −1,260 volts.

The Hornyak button was 1 in. in diameter and 0.10 in. thick. Preliminary measurements showed that a thicker button gives poorer gamma discrimination since the range of recoil electrons from γ-ray Compton interactions is much greater than the range of recoil protons from fast-neutron interactions. Also, it was thought that, with a larger button diameter, neutrons could stream around a small pipe and strike the button, decreasing the sensitivity.

Two polonium-beryllium neutron sources were used, providing ~3×10^7 and ~5×10^5 neutrons/sec. A Co^{60} gamma source was used to study the effect of γ-rays on the measurement. One position of the unshielded gamma source resulted in 50 r/hr in the button, but because of the radiation hazard it was used in this position only for adjusting the pulse-height selector of the amplifier to provide adequate gamma discrimination. All other measurements were made with the source shielded so that the detector received only 1 r/hr.

Test Results

The data in Fig. 1 were taken with the 0.1-in.-thick button. The change in counting rate is maximum for the largest pipe, but still ~9% for the smallest pipe. The water level is easily read to ±1 cm. The level indicator used was accurate to only ±0.5 cm, and in addition some inaccuracies were introduced in aligning the source and detector. However, ±1 cm is well within the acceptable limits.

DATA OBTAINED with Detector in 50-r/hr γ Field*

Counting rate (cpm)	*Radiation field*	*Position of detector*
½-in. pipe, gain of 2, pulse height of 60		
26,600	γ background	above water
15,800	no γ	above water
1¾-in. pipe, gain of 2, pulse height of 40		
52,946	γ background	underwater
8,657	no γ	underwater
87,565	γ background	above water
13,563	no γ	above water
4-in. pipe, gain of 2, pulse height of 28		
204,355	γ background	underwater
5,164	no γ	underwater
301,950	γ background	above water
15,248	no γ	above water
4-in. pipe, gain of 4, pulse height of 70		
17,525	γ background	underwater
1,711	no γ	underwater
29,941	γ background	above water
3,808	no γ	above water

* The larger neutron source (3×10^7 neutrons/sec) was used with the Co^{60} gamma source in such a position to provide flux of ~50 r/hr at the Hornyak button.

To simulate an operating gamma flux, a Co^{60} source placed near the photomultiplier tube gave a flux of ~1 r/hr in the button. Figure 2 indicates the result of this experiment. Except for an increased counting rate, the shape of the curve with the gamma source present is similar to that without the source. This, together with the ~50-r/hr data of the table, indicates that the gamma response could be discriminated out sufficiently to permit successful measurements. A tentative explanation for the increased counting rate is that the addition of coincident gamma pulses to the neutron pulses in the A-1 amplifier raised the level of the neutron pulses, enabling more of them to be counted at a given pulse-height setting.

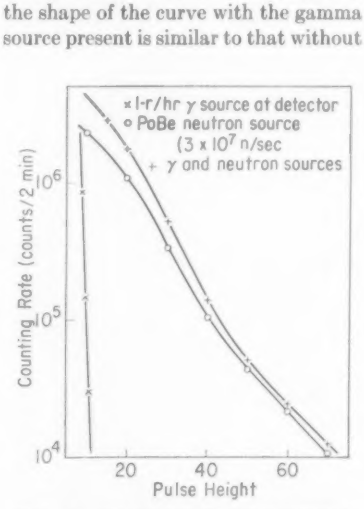

FIG. 3. GAMMA-DISCRIMINATION properties of Hornyak button (light water in ¾-in. pipe; detector 9.4 cm below liquid level; gain of 2)

Several points were taken with the Co^{60} source resting directly on the photomultiplier tube. This produced a dose rate of ~50 r/hr in the button. The gamma response from this dose rate was discriminated out at gains of 2 and 4 on the A-1 amplifier; other settings were not attempted.

Because of the radiation hazard with the Co^{60} source in this configuration, the water level was not changed in these cases. Instead, one point was taken above the water level and one point below, with the source removed during level adjustment. Exact repositioning of the gamma source was not possible; thus the two points taken cannot be compared graphically but are presented in the table. It can be noted from the table that, at a gain of 2 and a pulse-height setting of 60, the counting rate with the gamma source present is less than twice that of the neutron source alone. Figure 3 shows that the gamma response of the Hornyak button falls off very sharply with pulse-height setting. This means that the gamma counts can be greatly reduced at the higher pulse-height settings.

Additional measurements indicated that the differences between neutron attenuation by light and heavy water are small and insignificant for this application.

Future Tests

A remotely manipulated and waterproof device will be constructed so that further tests can be made under conditions more like those of an operating reactor. Furthermore, the thickness of the Hornyak button can be decreased to provide still better gamma discrimination at high gamma flux levels. Thicknesses down to ~20 mills seem usable. For the smaller diameter buttons, a smaller photomultiplier, such as an RCA 6199, may prove more convenient. Better gamma discrimination can also be obtained with a double-delay-line amplifier in place of the A-1 amplifier; this could be used to drive a counting-rate meter.

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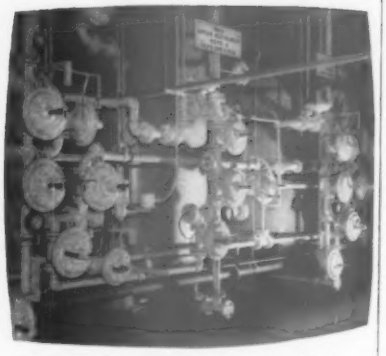

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1942 By this time, IWT had already built more than 50 successful multi-bed ionXchangers (some of which are still in use today).

1943 IWT brought "automation" to ionXchange with the introduction of automatic ionXchangers, some of which were very large. (Some of *these* are still operating today, also.)

1947 This was the year when IWT brought out the first large (400 gpm) ionXchanger for silica removal.

1949 IWT built the first commercial *Mixed Bed* ionXchanger.
(U.S. Patents 2605084 2771424)

1954 A huge 5,000 gpm fully-automatic mixed-bed ionXchanger was designed and built by IWT to remove silica from make-up water for high-pressure boilers. This plant has now de-ionized over SIXTY BILLION pounds of water.

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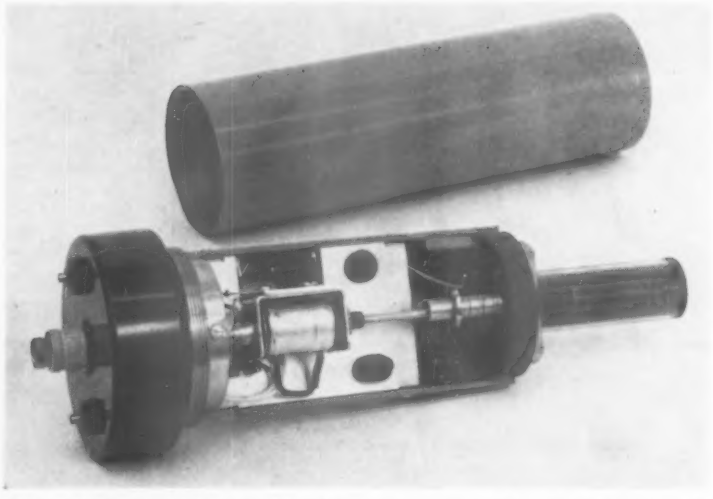

FIG. 1. PROBE containing transistor circuits mounts on wall bracket for area monitoring and can be removed for bench-top surveys

Transistorized Area Monitor Uses G-M–Ion-Chamber Probe

H. A. BROWN and J. V. ROGERS, *Tracerlab, Inc., Richmond, California*

Our new area-monitoring system uses up to 10 remote probes (Fig. 1) feeding their information to a central alarm and observation station (Fig. 2). Gamma-photon detectors in the probes are designed to operate as halogen-quenched G-M counters at low radiation levels and as ionization chambers at higher levels. The result is a system that has a logarithmic response from 0.1 mr/hr to 10 r/hr (*1*).

This system has the following advantages:

1. No zero adjustment
2. No zero drift
3. Minimum of calibration adjustments
4. Simplicity
5. Reliability and reproducibility

The remote probes have a design due to Pearson (*2*). They can be placed on wall brackets and connected to the central station by up to 2 miles of cable. For local monitoring one can plug either an alarm light or a light-and-meter combination into the probe and remove the probe from its bracket to scan for suspected contamination. Radiation levels can be read continuously, even after a preset alarm has been tripped.

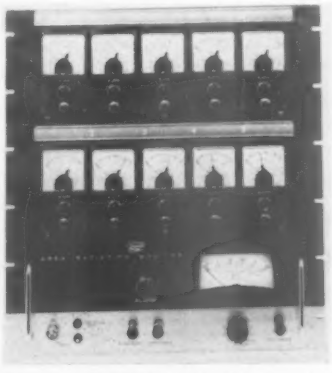

FIG. 2. CENTRAL STATION has control and power-supply chassis at bottom, up to 10 plug-in indicators above

Probes

Each probe is a moisture-proof sealed unit containing the detector and its

transistor circuits. Figures 3 and 4 show the mode of operation.

In the range 0–50 mr/hr the counting signal predominates. Each count triggers a transistor multivibrator, and the multivibrator output is rectified by diode pumps to produce an output current depending on counting rate. Meanwhile the ionization current through the detector is added to the counting-rate output, and this signal is predominant at intensities above 50 mr/hr. Figure 5 shows the three resulting responses: counting rate-signal, ionization current and the sum of the two, which is the net output.

The probe assembly has been tested over a temperature range of −10°–85° C and shows only a 2% change in current output. The detector is not damaged by overvoltage or high radiation intensity. Output current is 100 μa at 10 r/hr. This is great enough that the effect of cable leakage is negligible.

Sr^{90} sources are provided for checking and calibration. The checking source is installed as part of each probe and can be moved into position by means of a solenoid controlled by push button from the central control station.

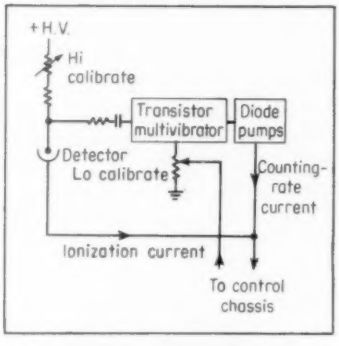

FIG. 3. PROBE CIRCUIT combines counting-rate signal and ionization current to make 5-decade logarithmic response in net output

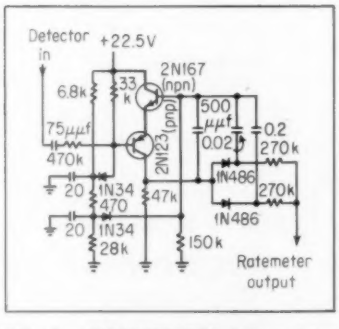

FIG. 4. MULTIVIBRATOR followed by diode pumps is ratemeter circuit

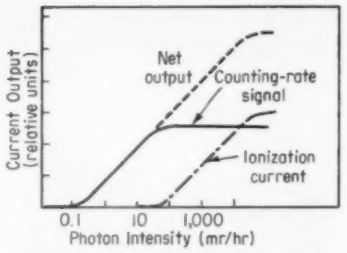

FIG. 5. NET OUTPUT is sum of two signals and is accurately logarithmic for 5 decades

Calibration requires adjustment of the two potentiometers shown in Figs. 1 and 3. This is done by one man at the probe using two standard sources designed to slip over the end of the probe. He observes the reading of the probe with a plug-in calibration meter connected to the accessory plug visible in Fig. 1. Calibration is required only monthly or less frequently. Once calibrated the probes can be interchanged without losing accuracy.

Two auxiliary devices are designed to be mounted on the probes and connected to the 7-pin accessory plug. One is a local alarm light that repeats the signal appearing at the central station. The other has both a light and a meter. Full scale on the meter represents a radiation intensity of 10 r/hr.

Central Station

The central monitoring station of Fig. 2 has a control chassis at the bottom and up to 10 plug-in station indicators above it.

Inexpensive intercom cable connects the probes to the control chassis. This chassis includes power supplies, master metering for all channels, check-source control, master-alarm circuitry and recorder outputs.

Output current from each probe is measured continuously by a simple meter relay. Five of the meter-relay units can be nested in a standard auxiliary chassis as shown in Fig. 6. The units are designed for two ranges—100 mr/hr or 10 r/hr full scale.

A pointer on each meter-relay can be set to determine the alarm level. The master meter on the control chassis can be switched to any channel for readings above the alarm level.

A single power supply develops 480 volts for the detectors. It is regulated to better than 0.1% over a line-voltage range of 90–130 volts; 22.5 volts for the transistors is derived from the 480-volt line. Circuits are designed so that an

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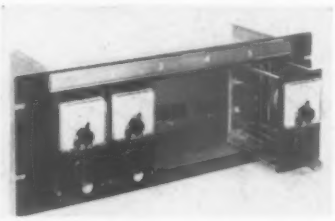

FIG. 6. STATION INDICATORS plug into standard racks. Each has meter relay and alarm light

electrical or physical accident in one probe will not affect the others. 150 volts d-c is also provided for operation of the alarm system.

Alarm System

An alarm is initiated by a high radiation level at one of the probes or a power failure. When this occurs, a large master light on the control chassis is illuminated, a small pilot light on the meter-relay panel involved is illuminated and the light at the probe is illuminated (if there is one). Switched 115-volt outlets are available at the back of the control chassis to power visual and audible alarms. A front-panel button disables the audible alarm; the visual alarm can not be disabled.

When an alarm occurs, a motor-driven interrupter starts and at 6-sec intervals allows the meter relays to reset themselves. On a successful resetting of the meter relays, all alarms cease except for the "memory" light on the meter-relay panel involved. The audible alarm is re-enabled and is automatically in readiness for future alarms. To extinguish the memory light an alarm-reset button must be depressed.

If an alarm is caused by failure of the 480-volt or 150-volt supplies, a small pilot light on the control chassis goes on. The operator can then use the master meter on the control chassis to determine which supply has failed. A special scale on the meter and two special positions on the selector switch that goes with it are provided for the purpose.

Performance

When one of the probes is suddenly exposed to radiation the system response in time is approximately exponential with a 1.8-sec time constant. Full-scale response, either up or down, requires less than 5 sec. This is almost twice as fast as other types of monitors we have studied.

We have tested the dependence of the response on photon energy from 0.28 to 1.2 Mev. Extrapolation of the data indicates that between 0.08 and 3 Mev one can expect photon-energy dependence of $\pm 20\%$. Calibration drift is less than 10% per month.

The present system was developed after we had investigated the performance of this and two other promising systems with breadboard models. One of the others uses an ion chamber, a vibrating capacitor, and a servo amplifier. It is like the Oak Ridge Area Monitron but differs by having logarithmic response. With careful design the system is capable of excellent stability. However, each station requires a vibrating reed, a servo amplifier and a servo motor; so it is very expensive for a multi-channel system.

Another system we developed uses an ion chamber and a vacuum-tube electrometer. A differential amplifier design takes care of drift and aging of electrometer tubes. A chopper converts the d-c output of the electrometer to exponential pulses to provide logarithmic response. This system is less expensive than the vibrating-capacitor one, but drift is a considerable problem. Drift results from both tube aging and voltage changes.

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2. I. L. Fowler, A. Pearson, L. A. K. Watt, NUCLEONICS **17**, No. 1, 78 (1959); I. L. Fowler, AECL Report GPI-36 (May, 1956)

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* * *

Tungsten carbide powder is now available from Union Carbide Metals for evaluation in the manufacture of cemented or sintered carbide tools, dies and other compacts. Produced by a patented single-stage process, it meets existing particle size and chemical specifications for powders now produced by conventional methods. Data Sheet WC1-N gives additional facts.

* * *

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* * *

Applications of chromium monoboride are being explored with prospective users by Union Carbide Metals Company's field men. The compound's low volatility and high reflectivity make it attractive for several purposes. Coatings of chromium monoboride can be applied by metallizing methods. Evaluations of these coatings have proved them satisfactory where resistance to high temperatures, erosion, and corrosion are required. Chromium monoboride has also been used as a constituent of super alloys, such as those containing alloys of chromium, nickel and boron. Data Sheet CM1-N gives additional information.

* * *

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* * *

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APDA Introduces Statistical Hot-Spot Factors

EDITORS' NOTE: *The following article grew out of a luncheon discussion group organized by* NUCLEONICS *during this year's Nuclear Congress in Cleveland. Although the group originally had intended to discuss hot-spot calculation practices in general, APDA's new statistical approach turned out to be the main topic of conversation. More detailed articles in this important subject area will follow.*

DISCUSSION GROUP listens to John Herb (APDA), extreme left, explain new hot-spot factor method. From left to right, NUCLEONICS Associate Editor and discussion leader Hal Davis (at far end of table); Ralph Grimble representing Westinghouse-Bettis; W. S. Farmer from ACF; Corwin Rickard (back to camera) of General Atomic. Not shown is Charles Graves from NDA

The Enrico Fermi Fast Breeder Reactor is the first reactor to use hot-spot factors calculated on a statistical basis. Like other reactor groups, Atomic Power Development Associates (APDA, designer of the EFFBR) lumps the temperature deviations that could be caused by the many uncertainties in core parameters into an over-all hot-spot factor that gives the maximum temperature deviation in any part of the core from the nominal design value. Unlike other groups, who calculate this factor by simply adding together the contributions from the various uncertainties, APDA combines the contributions according to statistical principles. When the reactor is in operation, APDA will use the results to estimate the allowable residence time of fuel subassemblies.

One of the benefits is that APDA is able to quote a definite number for the probability that the actual hot-spot temperature will not exceed the calculated value. An even more impressive reward is that with the new method APDA is able to justify a hot-spot factor of less than 1.2—instead of the 1.5 that the traditional method would give. The difference means an automatic 25% increase in the design output power. Other reactor designers have expressed interest, but also caution, about applying the method to their own reactor projects. However, with bonuses of this size at stake, there will be strong motivation to adopt APDA's approach in some form.

At a recent NUCLEONICS-sponsored discussion of hot-spot factors (see photo), John Herb of APDA explained that the gain in performance is possible because older methods for calculating hot-spot factors are unnecessarily conservative. These methods always, in effect, assume that the extreme values of the uncertainties all occur at the same point in the core—that the same fuel element will have the worst deviations in both uranium loading and dimensions, and will be located in the channel with the poorest coolant supply in the region of highest deviation of neutron flux, and so on. The APDA method holds that the probability of these independent extremes all occurring at one point in the core is usually very small. By replacing this extreme criterion with a more realistic one that takes advantage of the more likely and more favorable statistical combinations, APDA is able to reduce the over-all hot-spot factor and hence up the performance.

APDA first agrees on an explicitly stated figure for the confidence level or probability that the hot-spot temperature will by chance exceed the limit to be calculated. Usually, APDA uses a confidence limit of 99.87%, equivalent to 1.3 chances in 1,000. Then APDA calculates the deviation expected within this confidence limit for each of the hot-spot contributions and combines the deviations statistically (taking the square root of the sum of the squares of the variations) to produce a final hot-spot temperature that satisfies the agreed-on confidence level. In physical terms this confidence level means that one fuel pin out of a thousand may exceed the calculated temperature. Because the hot-spot calculation applies to the central fuel sub-

Just What Is a Hot-Spot Factor?

When a reactor is in the lines-on-the-blackboard stage, its core is presumed to be a perfect structure: the fuel elements all have precisely the same dimensions; each enjoys a specified coolant flow and experiences a known neutron flux. As the design advances, the designer at some point has to face reality: real-life fuel elements will vary from one another in dimension, the coolant flow will not distribute itself exactly as planned, and the neutron flux may not agree with predictions. The hot-spot factor has, by tradition, become the link between reactor performance calculated on the blackboard and the performance expected from the actual plant. For each of the physical characteristics of the core, one estimates the maximum change in the performance-limiting parameter (usually a temperature in the core) that could be caused by real-life deviations from the ideal value of the characteristic. These separate effects are then combined into an over-all "hot-spot factor" which multiplies, say, the nominal maximum core temperature to give the realistic temperature.

Typical APDA Hot-Spot Calculation Using Statistical Method

Nominal values→ / *Physical Uncertainty* ↓	*Coolant temp. rise* ΔT_c = 285° F		*Temp. drop thru film* ΔT_f = 41.5° F		*Temp. drop thru oxide layer* ΔT_o = 15.5° F		*Temp. drop thru clad* ΔT_{Zr} = 39.8° F		*Temp. drop thru fuel* ΔT_U = 196° F		*Summary*	
	F	3σ (°F)	F	3σ (°F)	F	3σ (°F)	F	3σ (°F)	F	3σ (°F)	Σ(3σ) (°F)	[Σ(3σ)]² (°F²)
Maldistribution of coolant (a) to subassemblies	1.15	42.8									42.8	1,831.8
Maldistribution of coolant (b) within subassemblies	1.03	8.6									8.6	74.0
Deviation from nominal dimensions			1.04	1.7							1.7	2.9
Deviation from nominal dimensions					2.00	15.5					15.5	240.3
Deviation from nominal dimensions							1.02	0.8			0.8	0.6
Deviation from nominal dimensions									1.02	3.9	3.9	15.2
Maldistribution of U^{235}	1.02	5.7	1.02	0.8	1.02	0.3	1.02	0.8	1.02	3.9	11.5	132.3
Maldistribution of flux	1.05	14.3	1.05	2.1	1.05	0.8	1.05	2.0	1.05	9.8	29.0	841.0
Burnup in core fuel pin	1.10	28.5	1.10	4.2	1.10	1.6	1.10	4.0	1.10	19.6	57.9	3,352.4
Power measurement and control	1.08	22.8	1.08	3.3	1.08	1.2	1.08	3.2	1.08	15.7	46.2	2,134.4
Film-heat-transfer coefficient			1.30	12.5							12.5	156.3
Thermal conductivity of zirconium oxide					1.20	3.1					3.1	9.6
Thermal conductivity of zirconium							1.10	4.0			4.0	16.0
Thermal conductivity of fuel alloy									1.20	39.2	39.2	1,536.6
											Total	Σ[Σ(3σ)]² = 10,343.4
											(Sq. root of total = 3σ) =	101° F
											Total hot-spot deviation =	**101° F**

Uranium hot spot located at fuel-alloy-length fraction, X/L	= 0.70
Nominal maximum uranium temperature (without hot-spot factor)	= 1,134° F
Hot-spot factor	101
Maximum uranium temperature (99.87 % confidence)	1,235° F

assembly, which contains 144 pins, APDA expects one fuel pin in every fifth central subassembly to run hot.

One might object that even this risk is still too high for anyone in the reactor business to take. Herb pointed out, however, that exceeding the temperature limit does not automatically mean failure. This limit is, itself, usually conservative—i.e., operation below allows one to achieve the predicted burnup, while extended operation somewhat above merely reduces the residence time. Thus the 1-in-a-1,000 risk is a second-order affair. Should a fuel pin fail because of overheating, the result is still far from catastrophic. At worst a reactor might have to be shut down so that the assembly with the bad pin could be removed and the system cleaned up. Even this might not be necessary; for instance, PWR has been running with a failed blanket element for a number of months.

Typical Calculation

The table summarizes the results of a typical hot-spot-factor calculation by APDA for the Enrico Fermi reactor. In this instance the centerline temperature of the fuel pin is the limiting consideration. The calculation refers to the pins in the central subassembly where the neutron flux is a maximum. The left-hand column lists the various physical factors that give rise to uncertainties in this temperature. The next five columns list the extreme uncertainties introduced by these factors in the nominal temperature drop (given at the column head) across each of the five regions in the heat-flow path. Each extreme is expressed in two ways: the columns headed *F* list the factors that multiply the nominal ΔT to give the "hot" ΔT; the columns headed 3σ list the actual difference (in °F) between the "hot" and nominal ΔT's.

Possibly the only clue that the procedure differs so far from the ordinary approach to calculating hot spots is the column heading "3σ." In arriving at the numbers in the columns labeled 3σ, APDA assumes that each of the quantities listed in the extreme left-hand column has a Gaussian or normal probability distribution about its nominal value. In each case APDA makes an estimate of the deviation from the nominal value that corresponds to three times the standard deviation of the distribution. The number listed in the 3σ column then is the temperature elevation caused by this "3σ" deviation in the physical quantity.

The table shows that the same physical effect can cause temperature elevations in more than one of the five regions. When these temperature changes are causally linked (i.e., not statistically independent), as for maldistribution of flux, the changes are added together to give the total temperature elevation for that particular physical effect in column $\Sigma(3\sigma)$. When the changes are statistically independent, as for variations in fuel-element dimensions, each regional temperature elevation is listed in the $\Sigma(3\sigma)$ column separately.

At this point the conventional method of calculating hot-spot factors would proceed by adding the totals listed in column $\Sigma(3\sigma)$ to produce a total over-all hot-spot temperature elevation. (In the present example, a total elevation of 277° F would be calculated in this way.) However, APDA argues that the contributions listed in the $\Sigma(3\sigma)$ column are statistically independent and that the proper way to combine them (see box) is to take the square root of the sum of the squares. This calculation (carried out in the last column) yields a total hot-spot elevation of only 101° F compared with 277° F above; in terms of hot-spot factors, the statistical method gives 1.2 while the conventional method gives 1.5. Because the 101° F result is formed by combining 3σ deviations,

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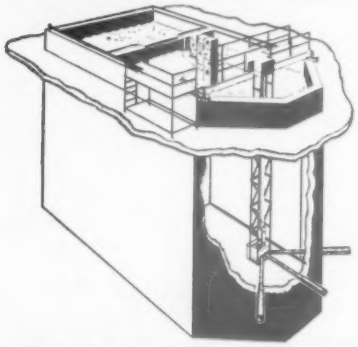

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This article starts on page 92

it has a confidence level (corresponding to 3σ's for a normal distribution) of 99.87% (~1 in a 1,000).

Input-Data Reliability

Representatives of four other reactor design companies present at the discussion reported that their groups do not use a statistical calculation like APDA's for the over-all hot-spot factor. Ralph Grimble (Westinghouse-Bettis), who was one of the first persons in the literature to suggest a statistical approach,* commented that there was nothing wrong in principle with APDA's method but that his group desires to retain the extra safety provided by the more conservative approach of multiplying the F's together directly [equivalent to adding the temperature deviations in the $\Sigma(3\sigma)$ column]. The three other reactor designers present (ACF, GA and NDA) also saw nothing wrong in principle with APDA's statistical arguments; they expressed doubt, however, that the input data were reliable enough to justify APDA's refined calculation. They felt it would be better to stay with the more conservative practice of adding the temperature deviations directly until more is known about the contributing effects.

In reply, Herb (APDA) said that he believed the statistical method was useful at "any stage of the game." He agreed that one has to be conservative where the data are uncertain but that this conservatism is best reflected in the selection of the 3σ temperature limits for the individual effects and not in the method of combining them. His view is that one can be quite conservative (as he feels APDA has been) in estimating these input limits and still realize important savings by using the statistical method of combining these factors.

Herb explained that input data for the APDA calculations fell into three

* B. W. LeTourneau and R. E. Grimble, Engineering Hot Channel Factors for Nuclear Reactor Design, *Nuc. Sci. and Eng.* **1**, No. 5, 359 (1956).

Calculating the Standard Deviation of a Sum

Central to APDA's method of hot-spot factor computation is the argument that the variance (the standard deviation squared) of the sum of two or more statistical quantities is equal to the sum of the individual variances. To see this consider two statistical quantities X and Y with probability distributions $g(X)$ and $f(Y)$. X might correspond, say, to the temperature deviation associated with the uncertainty in a fuel-element dimension and Y the temperature deviation associated with uncertainty in the fuel thermal conductivity. We know that $\int_{-\infty}^{\infty} g(X)dX = 1$ and $\int_{-\infty}^{\infty} f(Y)dY = 1$. If the means of the two distributions are both zero (as they would be for the two temperature deviations), then

$$\mu_x = \int_{-\infty}^{\infty} Xg(X)dX = 0 \text{ and } \mu_y = \int_{-\infty}^{\infty} Yf(Y)dY = 0$$

and the individual variances are defined by

$$\sigma_x^2 = \int_{-\infty}^{\infty} X^2 g(X)dX \text{ and } \sigma_y^2 = \int_{-\infty}^{\infty} Y^2 f(Y)dY$$

We want to determine the variance for the statistical quantity $Z = X + Y$. If X and Y are statistically independent then the probability distribution function for Z is $h(Z) = \int_{-\infty}^{\infty} g(X)f(Z-X)dX$. The variance of Z is

$$\sigma_z^2 = \int_{-\infty}^{\infty} Z^2 h(Z)dZ = \int_{-\infty}^{\infty} Z^2 dZ \int_{-\infty}^{\infty} g(X)f(Z-X)dX$$

If we change the order of integration and substitute $Z = X + Y$ we get $\int_{-\infty}^{\infty} g(X)dX \int_{-\infty}^{\infty} (X^2 + 2XY + Y^2)f(Y)dY$. Using the above definitions to evaluate the inside integral

$$\sigma_z^2 = \int_{-\infty}^{\infty} g(X)(X^2 + \sigma_y^2)dX$$

Integrating again we get finally

$$\sigma_z^2 = \int_{-\infty}^{\infty} X^2 g(X)dx + \sigma_y^2 \int_{-\infty}^{\infty} g(X)dX = \sigma_x^2 + \sigma_y^2$$

broad classes—(a) uncertainties for which the statistical distributions are accurately known, (b) uncertainties for which the 3σ limit is estimated from the spread of experimental data, and (c) uncertainties for which only a rough estimate of the maximum deviation is available. An example of (a) would be the uncertainty in a fuel element dimension, something for which data on a large number of samples is usually at hand; an example of (b) would be the uncertainty in film heat-transfer coefficient which was obtained by noting the limits on the spread of the available data plotted on a graph. An example under (c) would be the uncertainty in the neutron flux at a point; here the physics department has picked out a number which it judges to be a reasonable upper limit for the 3σ value. Most of the questions about APDA's hot-spot calculation had to do with whether or not the statistical method should be used with "type-(c) input." Herb claimed that, as long as such estimates were conservative (i.e., certain to include the 3σ limit), the statistical approach was justified. He said that APDA tried to make sure that the type-(c) estimates listed in the table were conservative by arbitrarily increasing any type-(c) estimates originally provided by the different engineering sub-groups.

Reactor Group Comments

Following is a roundup of comments by the other reactor designers present at the discussion on what they thought of the statistical method for their own reactors:

• **Ralph E. Grimble** (Westinghouse-Bettis Atomic Power Div., Supervising Engineer)

"I think this is a reasonable approach; we have examined some of our reactors refiguring the hot-channel factors on a statistical basis and it does turn out that you can lower them markedly. But the current limit we have on pressurized-water reactors is not so much the fuel temperature but rather the film-blanketing condition. So that the more important factors have to do with water-coolant temperature rise and with pressure drop. We have not entirely accepted the use of statistics in our group—we find it very difficult to settle on a probability level for failure. For instance, we think 1 in a 1,000 is probably too high to be acceptable in a naval reactor.

"On the other hand, you can't get away from the fact that statistics are built into reactors. Many of the inspections that have to be made on fuel elements are destructive and the only understanding that one can get as to whether or not tolerances are met for the elements you are going to use is through some kind of statistical treatment. Actually there is no absolute tolerance that one can point to and say that all dimensions in this reactor meet this tolerance. There is a certain finite probability that many of the tolerances are exceeded according to some statistical distribution. The ultimate logical approach is to translate these statistical numbers for tolerances into a statistical probability of failure, however you define failure—whether it's exceeding a certain temperature or having film blanketing occur.

"I'm impressed with the simplicity that appears to be possible here. I think the main reason that APDA can make the calculation this simple is because APDA is dealing strictly with temperatures which are additive and in this case temperature differences are linearly related to the F factors. Now in pressurized-water reactors where you are designing against burn-out you have several kinds of factors. So the over-all approach that you can take is not quite as straight-forward as APDA's. All the numbers have to be related to a probability of failure according to a number of equations that are sometimes approximate and nonlinear. I think this is a field in which a lot of work has yet to be done."

• **W. S. Farmer** (ACF project head for Elk River):

"I agree with John Herb to this extent, I think multiplying the F's is a very pessimistic approach. APDA's method is attractive for reactors like the research reactors where we have maybe ten or twelve different factors involved that are of the same order of magnitude and you want to avoid being unduly pessimistic. I think that for power reactors like the boiling water reactors, where we are using oxide fuel, we end up with only two limitations, one is the burnout heat flux and the other is the center-line temperature. The center-line temperature, for instance, has two major contributors: the temperature drop in the oxide and in the gas between the oxide and cladding. There is so much judgment involved in selecting the confidence limits for these effects I don't think that statistics at this point would simplify the problem any. You are trying to refine something that is already too uncertain in selection of the input parameters."

• **Corwin Rickard** (General Atomic; HTGR):

"I would think that until we have a better hold on the hot-channel factors the more conservative approach for us would be to multiply the factors out and concentrate the effort on reducing the value of the individual factors.

"The effect of these factors, of course, multiplies very rapidly in gas-cooled reactors—because of the large ΔT's across the core and large film temperature drops. Consequently we are extremely interested in decreasing the over-all factor. However, it doesn't seem to me that the right approach is to try to decrease the over-all factor by taking the statistical sum of the individual factors. A better approach is to try to obtain more knowledge on the individual factors so that they can be reduced. This is particularly true if one or two factors are controlling as is often the case."

• **Charles C. Graves** (NDA, Manager, Analysis Section)

"The statistical method seems to be a very reasonable approach for the future when there is enough experimental data and when the data has been analyzed to see where the statistical treatment is applicable. Many of the correlations and data now available don't appear to me to permit general use of this method. Therefore, the reactor designer, admitting his ignorance, will probably tend to use the conventional hot-channel analysis which is equivalent to assuming that the pessimistic values for all properties, correlations, flux ratios, etc., apply to his reactor.

"In the statistical treatment or, for that matter, the usual hot-channel analysis, there are dangers of misinterpretation because the person performing the analysis cannot always get a clear-cut definition of the uncertainties in the data, correlations, or calculated values that he uses. For example, the thermal conductivity of a reactor fuel under the expected reactor operating conditions may have to be inferred from out-of-pile tests. A correlation may be used outside of the range covered by the basic data. If the correlation does not give the correct functional behavior of the variables, a systematic as well as a random error occurs. Calculated values, for example, flux pattern, are subject to uncertainties associated with the input

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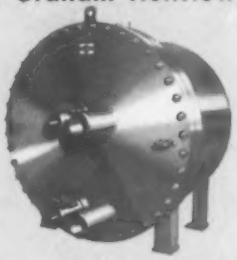

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data, with assumptions used to simplify the analysis and with the method of solution. The interpretation of these uncertainties is often quite subtle and sometimes impossible. In particular, the interpretation of the uncertainties to separate out the random from the systematic errors should be quite difficult. Since some uncertainties are not subject to a statistical interpretation, I would suspect that a reasonable compromise would be the use of the conventional hot-channel analysis for such uncertainties combined with the statistical treatment for those uncertainties which can be assigned values of statistical error."

Experimental Operation

In a sense, the improved performance authorized by APDA's hot-spot analysis is an improvement only on paper. Once a reactor is built and operating, the owners will go about determining the operating limits of that particular reactor by experimental methods. If the reference-design figures use the old-fashioned methods of hot-spot analysis and therefore, according to APDA, underrate the reactor, this fact will show up when the reactor begins to operate. Thus the conservative design approach would not permanently handicap performance. However, a more accurate prediction of the power in the design stage has unquestionable advantages. Competition in the market, alone, will probably force reactor designers to follow APDA's lead.

Scanning the Literature

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Metallurgy. Report (No. 8 in the series) on reactor technology developments. This one covers fuel, control and structural materials and process metallurgy. (KAPL-2000-5; $3.50*)

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Another Viewpoint—

Limited-Leakage vs. Canned-Motor Pumps

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EDITOR'S NOTE: *The imaginary roundtable discussion of limited-leakage vs. canned-rotor pumps that appeared in our May issue (NU, May '59, p. 138) suffered from the absence of a staunch defender of canned pumps. The author of the following comments has addressed himself to the problem created by that omission and offers some arguments in favor of canned-rotor pumps. Counter-comment by some of the contributors to the original roundtable is appended.*

I wish to comment on Table 1 of the May article and Dick's remarks about it. I am impressed by two things in the table: (1) that only a few pumps are listed, and these of relatively small capacity, and (2) it is quite evident that the larger the canned-motor pump, the smaller the cost differential. Since the pumps listed range in size from 30 to 400 hp, it seems to me Table 1 would have been more meaningful if it had included the full range of sizes. For example, up to 2,000 hp.

Relative Costs

Next I'd like to talk about Table 2 and Carl's remarks about that table. I am impressed by one thing in the table: the significant difference in cost ratio. Interestingly enough, this table shows that a canned-motor pump costs twice as much as a limited-leakage pump, while the maximum ratio in Table 1 is 1.6 to 1. Except for extremely small units, our experience is more in line with that shown in Table 1 and doesn't support the data shown in Table 2.

While we are discussing costs, I would like to explore the cost concepts on which a true functional comparison can be based. A canned-motor pump requires only electrical and cooling water services. In addition to the electrical and cooling-water services, the limited-leakage pump requires a motor, a high-pressure injection-sealing system, and a leakage collection and handling system. Therefore, to make a true cost evaluation of the two types of pumps, the additional cost of the above auxiliary equipment should be added to the initial cost of the limited-leakage pumps in Table 1.

I think my point of functional comparison should be extended to cover efficiency since Dick points out that canned-motor pumps have slightly lower efficiencies than limited-leakage pumps. While a discussion of theoretical efficiencies can be very interesting, the real point for consideration is, "How many total kilowatt hours does it take to perform the pumping function?" To show what I mean, the table below gives an actual evaluation made by a user on the basis of functional power demand in kilowatts for the two types of pumps.

From this it is quite evident that the canned-motor pump is, in reality, more efficient than the limited-leakage type—it requires 61 kw less to do the same job of pumping. Therefore, the point I'd like to make is this: it's only a matter of time until the higher operating costs eat up the initial cost saving.

Pump Power Demand

	Limited leakage	*Canned motor*
Power input to circulating-pump motors (kw)	704	762
Additional power input required to generate high-pressure seal fluid (kw)	119	—
Total power demand (kw)	823	762

Wear and Maintenance

Now I'd like to comment on bearing wear and maintenance. As Dick knows, the canned-motor pump bearings use water as a lubricant and are so designed that there is actually a film of water between the bearing surfaces. As a result, there is essentially no wear of the bearing parts during normal operation—as a matter of fact, we have inspected bearings after 40,000 hr of operation that showed negligible wear. Hundreds of canned-motor pumps in service have proved the reliability of the water-lubricated bearing.

Dick's statement that canned-motor pumps must be returned to the factory for repair does not recognize the advances made in canned-motor pump design in recent years. While the canned-motor pump was designed to operate continuously for long periods of time, we are now producing some models that can be completely rebuilt in the field within 24 hr using only hand tools. This includes replacing the stator winding. On the other hand, the maintenance of a limited-leakage pump can be a very serious problem. For example, the shaft seal has a limited life before it must be rebuilt or replaced. I have seen units in service today pumping nonnuclear, high-pressure, high-temperature water that have regularly required seal replacement in less than 12 months. Here is a case of known periodic maintenance that must be performed to keep the reactor operating.

I'm indebted to Art for bringing into the discussion the matter of forced-circulation systems in fossil-fuel plants because here is an application where the canned-motor pump is competing for acceptance with success. Although originally designed for pumping radioactive coolant water through a pressurized-water reactor system, the canned-motor pump is winning acceptance in fossil-fuel power plants because its lower total power requirements make for a higher plant heat rate. Additional benefits include: elimination of some piping and controls as well as maintenance of seals, lower operating and servicing cost, and adaptability to automatic station operation because

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there are no leakage control auxiliaries. As labor costs rise, the canned-motor pump will enjoy increasing acceptability because more and more utilities will turn to automatic operation of fossil fuel power plants.

In summary, then, it seems to me that limited-leakage pumps introduce additional operating problems and expenses that outweigh any apparent short-term advantages. It is my belief that experience will prove the hermetically sealed, canned-motor pump, which was designed specifically for primary-coolant pumping service in nuclear power plants, to be the more economical of the two types.

COMMENT on This Article

A. F. Erwin, Allis Chalmers:

"Hauser's comments appear applicable to the earlier buffer seals which have had a disappointing record of high leakage and frequent maintenance requirements. However, extensive tests of modern floating ring and sleeve seals, which also maintain a film of water between their surfaces for minimum wear, have demonstrated that low-leakage, low-maintenance seals of high reliability are now available. The penalty for seal inleakage becomes insignificant as this approaches the quantity of makeup which most reactors require due to radiolysis, control-rod leakage and other water losses. Furthermore the reactor makeup pump can be used in pressurized-water reactor plants to supply seal buffer water. And the boiler feed pump can supply seal water in boiling-reactor plants, resulting in essentially no additional auxiliary cost.

"It should be made clear that 'limited-leakage' does not mean leakage to atmosphere, as all of these seals have recovery seal chambers confining the leakage for return to system makeup tank; as to maintenance, the modern seal designs permit use of material that show long operating life expectancy under test and in plant operating experience. The type of wear or trouble that can be expected of these seals at worst is a gradual increase in clearances, which permits scheduled maintenance at times when servicing of other plant equipment is planned. The low efficiency evaluation cited by

Hauser is evidently based on a large inleakage of cold water to the system, which can be reduced to insignificant amounts with improved seals. The higher efficiency of buffer sealed pumps is consequently regained for full evaluation credit."

Bob Trout, Peerless Pump:

"Hauser may be considering an area of discussion which was not intended in our paper—namely, pumps using a buffer-seal arrangement where large quantities of injection water are required. The comments I made were for those seals where no supplementary buffer seals were required. It is necessary to differentiate the problems up to 1,000 psi and the problems for above 1,500 psi. Pumps operating at above 1,500 psi usually do need buffer seals, which leak very large quantities of water.

"When dealing with low-temperature water for buffer seal systems, and leakages of the order of magnitude of 10 gpm (a fairly realistic figure), the pumping power involved is ~18 h:p for 2,000-psi injection pressure and a pump efficiency of 70%. As the buffer seals wear, the leakage rates increase quite rapidly and frequently can use power at the rates that Hauser mentions.

"If cold injection water is not used but instead hot water from the reactor or boiler system is allowed to leak through the buffer seal, then the power loss can greatly exceed even those values mentioned in Hauser's comments. This system has other disadvantages and, to our knowledge, it is not in use.

"Therefore, we find ourselves in agreement with Mr. Hauser regarding the relative over-all performance as exhibited in his table, for pressures where buffer seals are required. For pressures where buffer seals are *not* required, however, we do not believe the seal pump needs to be penalized by any more than approximately 2 kw for the loss through the sealing system.

"Until seals can be developed that operate satisfactorily at pressures much higher than in present commercial use, without supplementary buffer seals, the canned-rotor pump has a real area of use at high pressures. The limited-leakage pump should be given consideration for intermediate pressures between 1,000 and 1,500 psi and the limited-leakage pump can operate satisfactorily at pressures below 1,000 psi."

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*Report to AEC Chairman John A. McCone by the Advisory Committee on Reactor Safeguards. Copies on request.

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Radiation Protection Standards Revised

Work on radiation-protection standards continues, and four publications appearing (probably) in 1959 have new numbers for health physicists' slide rules. These include Handbook 69 of the National Bureau of Standards which updates the bureau's earlier Handbook 52. The four reports contain the results of continuing work by the International Commission on Radiological Protection (ICRP) and the National Committee on Radiation Protection (NCRP) (*1-4*). Since these two groups work closely in harmony and have overlapping memberships, there are no significant differences among their recommendations.

All four of the reports contain recommendations only; they have no legal implications in themselves. In Handbook 69, for example, the Bureau of Standards emphasizes that it is conveying recommendations of others, not making its own. Biological and medical implications in the recommendations are outside the areas of competence of the bureau. Meanwhile the bureau has "cleared it" with the Atomic Energy Commission and the Public Health Service; it has made sure that there is no objection to publication from these agencies that may have overlapping responsibilities in enforcing radiation-protection standards.

One serious difficulty in calculating the values for radiation protection is a shortage of biological data. This will be somewhat alleviated by the appearance of a detailed bibliography of pertinent publications (*3*).

Changes

Three basic changes in radiation-protection philosophy are spelled out in the new recommendations: (1) Acceptable dose rates are based on quarterly rather than weekly limits. (2) Accumulated doses are limited by new age-dependent formulas. For example, accumulated whole-body exposures for radiation workers should not exceed $5(N - 18)$ rems (N is age in years) (*1*). Dose limits are prescribed for not only radiation workers but also whole populations and nonoccupational groups near nuclear installations.

Some of the numbers in Handbook 69 are smaller than in the old days; some are larger. For example, the maximum permissible body burden of P^{32} has gone from 10 μc in the 1953 recommendations to 6 μc in 1959. Sr^{90} now has a recommended maximum body burden of 2 μc instead of 1 μc. Tritium in the body should be limited to 1 mc rather than 10 mc. Calculations have been based on 50 years of continuous occupational exposure rather than 70 years.

ICRP Recommends

In its already published report (*1*) the ICRP refers to its assumption of responsibility for basic principles, leaving detailed technical recommendations to national committees such as the NCRP. Changes from earlier recommendations come largely from evidence indicating long-term somatic effects of radiation. Long-term effects apparently include incidence of leukemia and life shortening. Another influence is a belief that recovery plays a smaller part in radiation effects than was believed in former years.

The present report recommends different limits for three different groups of organs or tissues: (a) blood-forming organs, gonads and lenses of the eyes, (b) skin and thyroid, (c) all others. Occupational-exposure doses to the first group are limited to $D = 5(N - 18)$ cumulative and to 3 rems in any 13 consecutive weeks. Skin and thyroid doses are limited in occupational exposures to 8 rems in 13 weeks. Occupational exposure to other organs and tissues are limited to 4 rems in 13 weeks and 15 rems per year. Adults in the vicinity of controlled areas are to receive doses lower than 1.5 rems/year. Genetic considerations suggest that whole populations should be exposed to doses as low as possible; 10 rems to age 30 from all man-made sources appears to be an acceptable absolute maximum. With proper protection of the gonads in medical procedures, the ICRP feels that 5 rems to age 30 is an acceptable limit. This figure is a compromise between the ideal of zero and the requirements that may be imposed as a cost for nuclear-energy benefits. The report includes recommendations for special cases of various kinds but makes no attempt to deal with medical exposure.

Handbook 69

The new Bureau of Standards handbook lists the recommendations of the NCRP for meeting the principles established by the ICRP. It is intended to make the materials of a joint NCRP-ICRP study available for daily use. Complete results of the study will become available in a forthcoming ICRP report (*4*). Most of the 95 pages are devoted to tables of maximum permissible body burdens and maximum permissible concentrations (MPC's). About 240 radionuclides are covered—about three times as many as in the preceding handbook.

Maximum permissible body burdens and MPC's are calculated with assumptions of (a) a "standard" man, (b)

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occupational exposure at 168 and 40 hours a week, 50 weeks a year and 50 years of exposure, (c) "critical organs" (bone, total body, gastrointestinal tract, lungs), (d) a compartment model of the body in which each organ is assigned a biological half-life for the isotope in question, (e) relative-biological-effectiveness (RBE) factors of unity for beta, gamma and X-rays, 10 for alpha particles and 20 for recoil nuclei. Calculations are made for each isotope in both water-soluble and water-insoluble compounds. Final limits are set by considering the critical organ for the isotope in question. This in turn depends on the concentration in the organ, the essentialness of the organ, the damage to the organ by entry of the nuclide and the radiosensitivity of the organ. Among the entries for each nuclide the name of the organ or organs that are critical are printed in boldface type.

Special formulas enable computation of MPC's for known mixtures of nuclides in the body. All computations have been made in duplicate—one set for 40-hr/week exposure and one for 168-hr/week exposure. Further tables establish MPC's for air and water on the assumption of normal exposure of an individual to nuclides in his air and water supplies.

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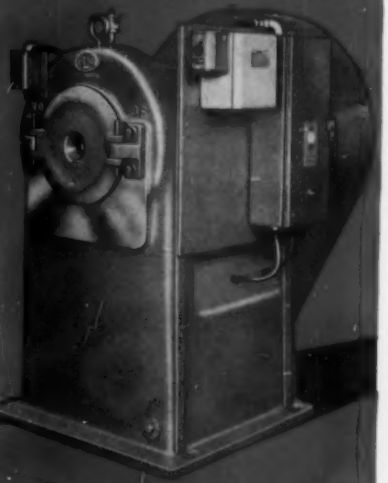

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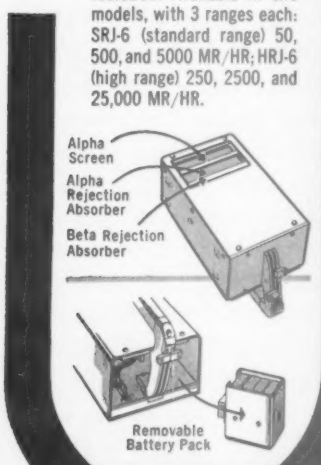

TECHNICAL ASSOCIATES

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Bulletin No. 159

Instrumentation for Nuclear Research
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Ceric Dosimetry: Accurate Measurements at 10^8 Rads

J. T. HARLAN* and EDWIN J. HART
Argonne National Laboratory, Lemont, Illinois

Ceric-sulfate solutions at high concentrations are suitable for measuring absorbed radiation doses up to 1.4×10^8 rads at dose rates of at least 10^6 rad/hr. [As indicated in the following article (*1*), the theoretical dose-rate limit is $\sim 10^{11}$ rad/sec.] Under controlled conditions reproducibility is within ~2% although batchwise variation in ceric-sulfate preparations may introduce larger errors (*1, 2*). Comparison of each new batch of ceric sulfate with a standard ferrous-sulfate sample is recommended. A comparison between ceric and ferrous dosimeters appears in the box below.

We use an 0.39-molar ceric solution. A nearly linear dose response exists up to at least 0.5×10^8 rads. At higher doses there is no question that the response is nonlinear; however, it can be accurately predicted up to at least 10^8 rads.

* PRESENT ADDRESS: Shell Chemical Corp., Torrance, Calif.

General Characteristics

Ceric-sulfate solutions have already found wide application as dosimeters. They are particularly suitable for the measurement of intense fields beyond the normal range of ferrous-sulfate (Fricke) dosimeters, ionization chambers and other common measurement methods. General characteristics of ceric dosimeters and the reaction mechanisms involved have been discussed (*2–8*), but there have been no previ-

Continued on page 107 (bottom)

Ferrous and Ceric Dosimeters—A Comparison

	Ferrous-sulfate (Fricke) dosimeter	Ceric-sulfate dosimeter
Field of usefulness	good absolute accuracy for low doses and dose rates	good relative accuracy for high doses and dose rates
Calibration of method	well established G-value for various types of radiation permits calculation of dose	at present requires calibration against absolute standard for each situation
G-value for 1-Mev gamma rays	15.6	1.7–3.1 (varies with concentration)
Upper limit of absorbed dose	50,000 rads	over 10^8 rads
Method of analysis	spectrophotometric	spectrophotometric or colorimetric titration
Relative ease of routine analysis	about the same	
Shelf life of dosimeter solution	days or weeks	months
Oxygen effect	solution must be aerated	no effect

Ceric Dosimetry: Routine Use at 10^5–10^7 Rads

SAMUEL I. TAIMUTY, L. H. TOWLE and D. L. PETERSON
Stanford Research Institute, Menlo Park, California

Ceric-sulfate dosimetry can be used for simple, accurate, routine measurements at 10^5–10^7 rads. With properly selected solutions, response is linear. Reasonable care will yield a precision of ±2%; with additional care precision of ±1% is possible. Our measurements have yielded results in substantial agreement with the preceding article (*1*) but our emphasis has been on routine use and a lower dose range.

We recommend the following procedure:

1. Prepare a ceric-sulfate solution of such concentration (0.001–0.05 *M*) that the radiation dose will reduce 20–80% of the available ceric ion
2. Irradiate in a bottle large enough to assure electronic equilibrium
3. Dilute with 0.8 *N* sulfuric acid
4. Measure optical density at 3,200 A
5. Compute the dose to the ceric solution
6. Compute the dose to the medium of interest

Method of Use

Our recommended procedure is not intended to imply that other procedures or deviations from ours will not yield equally reliable results. However, this procedure has proved to be satisfactory, and it is strongly recommended that the acceptability of any deviation be established by comparison with the ferrous-sulfate (Fricke) dosimeter. In fact, the acceptability of the techniques discussed here is based on routine periodic checking of the ceric-sulfate

TABLE 1—G-Values and Precision of Ceric-Sulfate Solutions

Reagent	*Average G-value**	*Standard deviation of mean*	*Standard deviation of individual determination*
G. F. Smith reagent ceric sulfate solid			
Lot No. 1	2.50	0.012 (0.5%)	0.041 (1.6%)
Lot No. 2	2.50	0.006 (0.2%)	0.021 (0.8%)
New solution of Lot No. 1	2.53	0.010 (0.4%)	0.029 (1.2%)
Baker and Adamson reagent ceric ammonium sulfate solid			
Lot No. 1	2.54	0.009 (0.4%)	0.030 (1.2%)
Lot No. 2	2.50	0.009 (0.4%)	0.031 (1.2%)
New solution of Lot No. 1	2.50	0.010 (0.4%)	0.032 (1.3%)

* Based on 12 determinations, except that values for new solutions of Lot No. 1 in both cases were the averages of 9 determinations.

TABLE 2—Stability of Ceric-Sulfate Solutions

Reagent	*Postirradiation change (%)**	*Preirradiation change in 0.1 M ceric stock (%)†*	*Preirradiation % change in 10^{-4} M ceric dilution†*
G. F. Smith reagent ceric sulfate solid	−1.9	+0.64	−5.4
Baker and Adamson reagent ceric ammonium sulfate solid	−3.4	+0.74	−4.4

* Over a 1-month period. † Over a 2-month period.

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This article starts on page 103

solutions against the ferrous-sulfate dosimeter. During our development program, routine use of the ferrous-sulfate dosimeter as a standard proved to be a powerful technique for revealing defects in the procedure and for tracing sources of error.

Spectrophotometric analysis is chosen as the analytical technique because in the range 10^5–10^7 rads it is faster and simpler than titration, and it is adequately precise. Since the dosimeter solutions must be diluted for optical analysis, two precautions should be observed. First, volumetric flasks used in the dilution should be calibrated to improve accuracy. Second, dilution should be done carefully since dilution factors as high as 200 may be required.

The effect of internal dimensions of the dosimeter vial has been pointed out (*2*). The effect arises because secondary electronic equilibrium must exist within the dosimetry solution (*3, 4*); essentially all of the secondary electrons that deposit energy in the solution must originate either in the solution itself or in surroundings that have identical energy-absorption characteristics. This condition can be assured for solutions in glass vessels by choosing the smallest internal dimension of the vessel large compared with the maximum range of the secondary electrons in the solution. Weiss has shown that for aqueous solutions irradiated with Co^{60} gamma rays the minimum permissible internal dimension is ~0.9 cm, or approximately twice the maximum range of the secondary electrons (*2*). If electronic equilibrium is assured, the absorbed dose in media other than the dosimeter solution can be readily calculated by application of the following equation

$$D_{med} = D_{ceric} \frac{{}_m\mu_{en} d \text{ (med)}}{{}_m\mu_{en} d \text{ (ceric)}}$$

where D_{med} and D_{ceric} are absorbed doses in medium and ceric solution, respectively, d is density, and ${}_m\mu_{en}$ is the mass energy-absorption coefficient (*5*).

The absorbed dose in the ceric-sulfate solution can be calculated from the measured change in optical density at 3,200 A through the following relation

$$D \text{ (rads)} = \frac{kD\Delta}{G\rho\epsilon}$$

$k = 1.6 \times 10^{-10}$ erg/100 ev $\times$ 6.02 $\times$ 10^{23} molecules/mole $\times$ 10^{-2} gram-rads/erg = 9.65×10^{11}; D = dilution factor (final volume/initial volume) of measured solution; Δ = change in optical density; ρ = density of undiluted solution (gm/liter); ϵ = extinction coefficient (optical density units/mole/liter); $G = G(Ce^{3+}) = 2.50$ molecules/100 ev.

Experimental Development

These recommendations come from a program to develop a standardized, reliable procedure for routine laboratory and production-plant use of the ceric-sulfate dosimeter in calibrating gamma-ray and electron-beam sources. It was hoped at the outset that a procedure capable of $\pm 5\%$ precision in routine use could be developed; the results exceeded our expectations.

Most of the irradiations were performed with a Co^{60} source at a dose rate of 3.60×10^5 rad/hr. Dose rates were measured with the ferrous-sulfate dosimeter (*6*) using $G(Fe^{3+}) = 15.6$. After exposure, the ceric dosimeter solutions and controls were diluted to $\sim 10^{-4}$ M to reduce their optical densities to values lying within the instrumental range. Then ceric concentration was measured by optical absorption at 3,200 A in a Beckman DU spectrophotometer (matched quartz cells, hydrogen-lamp attachment). The spectrophotometer extinction coefficient was determined from solutions of known ceric-ion concentration (measured by titration with standard ferrous ammonium sulfate).

All solutions were 0.8 N in H_2SO_4. Dosimeters were prepared by dilution from concentrated (0.1 M) ceric sulfate solutions which were kept on hand as working stocks. Dilutions were made with 0.8 N H_2SO_4. Solutions were stored in lighttight bottles to avoid photoreduction (*7*). The dosimeter solutions were irradiated in Pyrex weighing bottles to insure that the solutions were in contact only with glass surfaces. Prior to use, all glassware (Pyrex) was rinsed with singly distilled water, cleaned with hot concentrated nitric acid, and rinsed thoroughly with triply distilled water. This cleaning procedure was found to be essential to reliable measurements.

Water Purity

For reliable performance, it was necessary to use triply distilled water in preparing the ceric-sulfate solutions (Barnstead-still water redistilled twice from potassium permanganate/calcium oxide). Trace organic impurities can seriously affect the yield of Ce^{3+}. For example, 20 ppm of formic acid increases $G(Ce^{3+})$ from 2.50 to 3.55. Solutions made up with singly distilled water yielded erratic results. Attempts to stabilize solutions containing known organic impurities by adding more strongly oxidizing ions than ceric (sodium hypochlorite, silver sulfate, cobaltous sulfate, sodium bromate) were unsuccessful.

The ferrous-sulfate dosimeter provides a useful technique for determining whether a tripie distillation is adequate. This dosimeter is sensitive to the presence of organic impurities if sodium chloride is omitted from the solution. Water purity is satisfactory if ferrous-sulfate solutions with and without sodium chloride yield the same results.

Accuracy and Precision

Our measurements indicate the accuracy and precision that can be obtained with the ceric-sulfate dosimeter. During the course of this program 112 measurements of G-value were made. The average of these measurements was $G(Ce^{3+}) = 2.50 \pm 0.026$ ($\pm 1\%$), where the precision measure is the standard deviation of an individual measurement. It is important to note, however, that all 0.1 M stock solutions were checked against the ferrous-sulfate dosimeter on preparation and periodically during use. Solutions that yielded results differing by more than $\pm 4\%$ from those obtained with the ferrous-sulfate dosimeter were arbitrarily discarded as unsatisfactory. Until some means is found for eliminating the impurity sensitivity of ceric sulfate solutions, periodic checks against the ferrous-sulfate dosimeter are essential for reliable performance.

Of the five commercially available ceric reagents that were studied, only two were consistently accurate, precise, and stable. These were G. F. Smith reagent ceric sulfate (solid) and Baker and Adamson reagent ceric ammonium sulfate (solid). The behavior of solutions prepared from two lots of each of these reagents is given in Tables 1 and 2.

Rate, Energy, Temperature

The dosimeter is essentially independent of dose rate and radiation energy. It shows some temperature dependence above 35° C.

The yield of the dosimeter was measured calorimetrically (*8*) at electron dose rates up to 2×10^6 rad/sec

average and 2×10^8 rad/sec instantaneous (10-μsec pulses). No dose-rate dependence was found. The theoretical limit for freedom from rate dependence is $\sim 10^{11}$ rad/sec.

The yield was measured with Co^{60} gamma radiation and electron energies of 1, 8, 10, 18 and 24 Mev. Within measurement precision ($\pm 1\%$ for Co^{60} irradiations; $\pm 4\%$ for 1-Mev electrons; $\pm 7\%$ at higher energies) the yield was found to be independent of energy.

The temperature dependence of the yield of 0.03 *M* solutions irradiated to doses of 5×10^5 rads was measured at temperatures ranging from 7° to 61° C. Within experimental error, the *G*-value is constant below 35° C. A steady decrease is observed at higher temperatures ($G = 2.5$ at 27° C, 2.23 at 61° C). Thus, it is advisable to apply a temperature correction ($\sim 12\%$ at 61° C) if the dosimeter is used at elevated temperatures. The following values illustrate the temperature dependence:

Temperature (° C)	*G-value*
7	2.55 ± 0.06
16	2.50 ± 0.08
27	2.50 ± 0.09
35	2.43 ± 0.07
40	2.40 ± 0.04
50	2.31 ± 0.15
61	2.23 ± 0.07

Concentration Linearity

We feel that efficient use of the dosimeter in a production plant or laboratory where a great number of dosimetric measurements are performed requires a minimum number of standard ceric concentrations selected to span the dose range (10^5–10^7 rads). Thus each solution will be used for a range of doses, and the amount of ceric depleted will range from a small fraction of initial concentration at lower doses in the range to a large fraction at higher doses. Consequently we had to establish that solutions with a given initial concentration gave accurate *G*-values throughout the dose range for which they were designed. Linearity throughout the range of doses and concentrations was also investigated.

To check these points, 0.015 *M*, 0.003 *M*, 0.03 *M*, and 0.05 *M* solutions were prepared. A quantity of each solution was irradiated until $\sim 80\%$ of its ceric-ion content was depleted. Aliquots of each solution were taken at times during the irradiation corresponding to ceric depletion in the range 20–80%. Within

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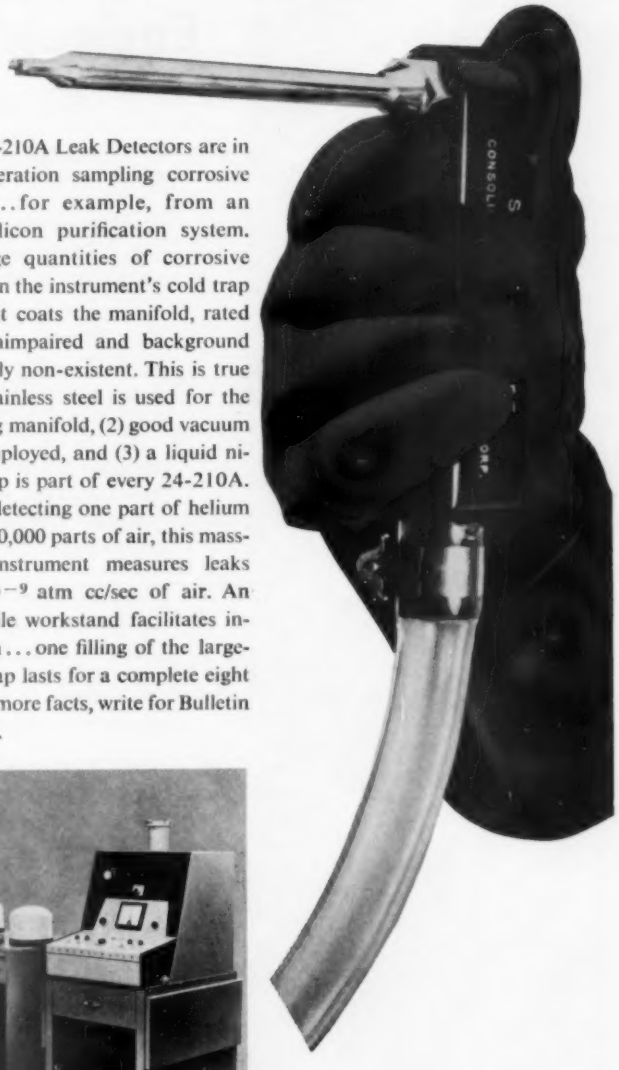

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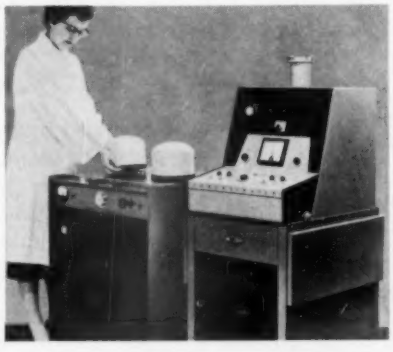

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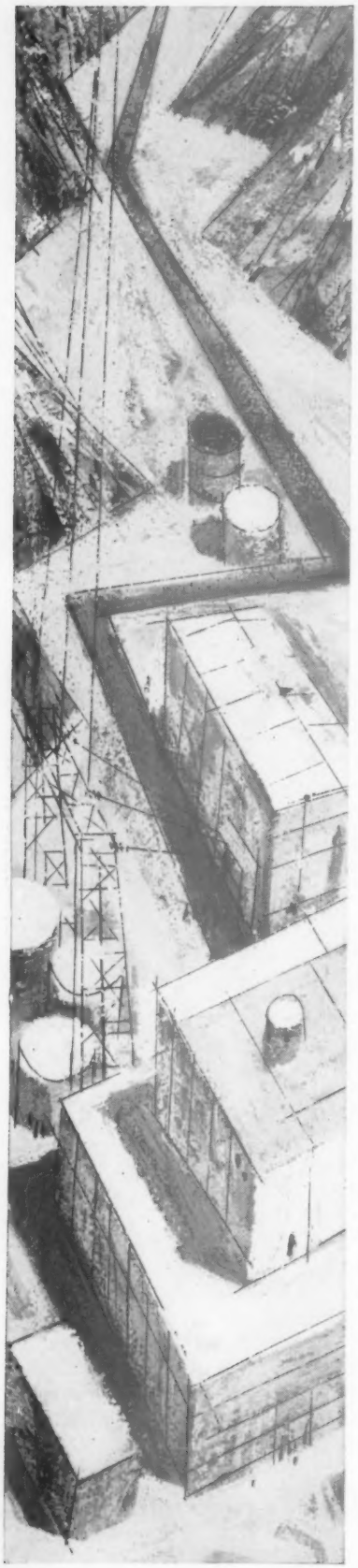

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This article starts on page 103

experimental error (±2%), the reduction in ceric concentration (micromoles/liter) was linear with dose throughout the range 10^5–10^7 rads. In addition the average of 16 measurements from the four solutions gave $G(Ce^{3+}) = 2.50 \pm 0.04$. Other experiments showed that 0.001 *M* solutions also give precise results. Thus, ceric-ion concentrations ranging from 0.001 *M* to 0.05 *M* are satisfactory. More dilute solutions are considerably more sensitive to impurities and photoreduction. The results also indicate that no difficulties are likely if the amount of ceric ion reduced by irradiation lies in the 20–80% range.

* * *

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This paper reports research undertaken in cooperation with the Quartermaster Food and Container Institute for the Armed Forces, QM Research and Engineering Command, U. S. Army, and has been assigned number 1025 in the series approved for publication. The views and conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense.

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Ceric Dosimetry: Accurate Measurements at 10^8 Rads

This article starts on page 102

ously published data to indicate the upper limit of their usefulness. We have undertaken to determine (a) the maximum doses that can be measured with ceric solutions and (b) the character of the response curves at large doses. We have investigated both high-level dosimetry and the radiation chemistry of concentrated ceric-sulfate solutions.

Upper limits of dose measurable with ceric solutions are set by ceric-ion solubility and complete reduction of ceric ion present. To study these limits we have exposed a series of solutions up to 0.6 molar in ceric ion to a Co^{60} source at a point where the dose rate is $\sim 10^6$ rad/hr (10^{21} ev/liter/min). Incidental observations made during the course of this work shed some light on the radiation-chemistry mechanisms involved at high ceric and cerous ion concentrations.

Chemistry. The primary effect of ionizing radiation on aqueous ceric-ion solutions is the reduction of ceric ion (Ce^{4+}) to cerous ion (Ce^{3+}). Most of the effect can be attributed to reaction of the cerium ions with the several oxidizing and reducing species produced during the radiolysis of water

TABLE 1—Effect of Composition of Solutions on $G(Ce^{3+})$

Solution	*Initial cerous/ceric ratio*	*Concentration (moles/liter)* Ce^{3+}	Ce^{4+}	H^+	$SO_4^=$	*Density (gm/ml)*	*Volumetric dose-correction factor* $\frac{m\mu_{en}d(\text{ceric})}{m\mu_{en}d(\text{ferrous})}$	*Initial* $G(Ce^{3+})$
A	0	0.0	0.39	2.4	2.0	1.15	1.10	3.1
B	½	0.2	0.39	2.4	2.0	1.20	1.15	2.6
C	8	0.16	0.02	2.0	1.2	1.10	1.06	1.9
D	0	0.0	0.1	2.0	1.2	1.09	1.055	2.9

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This article starts on page 102

(*2, 4–8*). However, direct interaction of radiation with solute becomes appreciable in more concentrated solutions. Ceric ions are reduced by H radicals and molecular H_2O_2, and cerous ions are oxidized by OH radicals. Thus the net reduction is the sum of these reactions; the relative contributions of each may vary depending on conditions.

The general radiolysis equation can be written

$$H_2O \rightarrow H_2,\ H_2O_2,\ H,\ OH$$

Reducing reactions are

$$H + Ce^{4+} \rightarrow Ce^{3+} + H^+$$
$$H_2O_2 + Ce^{4+} \rightarrow Ce^{3+} + H^+ + HO_2$$
$$HO_2 + Ce^{4+} \rightarrow Ce^{3+} + H^+ + O_2$$

Meanwhile the reoxidation reaction is

$$OH + Ce^{3+} \rightarrow Ce^{4+} + OH^-$$

If we represent the primary yields of H, OH and H_2O_2 (molecules/100 ev) in radiolysis by lower case g's, we have:

$$G(Ce^{3+}) = g(H) - g(OH) + 2g(H_2O_2)$$

Since ceric ions are reduced only by hydrogen atoms and H_2O_2 radicals, air (oxygen) does not affect $G(Ce^{3+})$. Organic impurities and certain inorganic ions may alter the above mechanism and thereby change $G(Ce^{3+})$. An increase in the ratio of cerous ion to ceric ion decreases $G(Ce^{3+})$ (*8*).

Experimental Procedure

We prepare ceric-sulfate solutions in the range 0.01–0.6 molar by dissolving $Ce(HSO_4)_4$ (G. F. Smith Chemical Co.) in 0.8 *N* H_2SO_4 (Baker and Adamson, 95–96.5 wt% C. P. reagent grade H_2SO_4 diluted with triply distilled water). For some tests cerous ion is added in the form of $Ce_2(SO_4)_3 \cdot 8H_2O$ (G. F. Smith Chemical Co.). The four solutions for which data are reported here have the compositions shown in Table 1.

Irradiations are carried out at 25°–35° C in 2-cm-diameter, 12-ml Pyrex cells sealed at the bottom and having an open capillary at the top. These cells are rotated on their axes and also in a circle about a cylindrical 1,500-curie Co^{60} source (*9*). Absorbed dose, determined by the ferous-ferric dosimeter in identical cells at the same geometry, is 1.22×10^{21} ev/liter/min = 1.15×10^6 rad/hr based on $G(Fe^{3+}) = 15.6$ (*10*).

Ceric-ion concentrations before and after irradiation are determined by

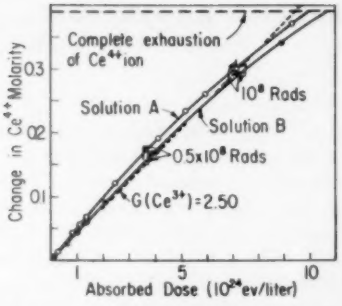


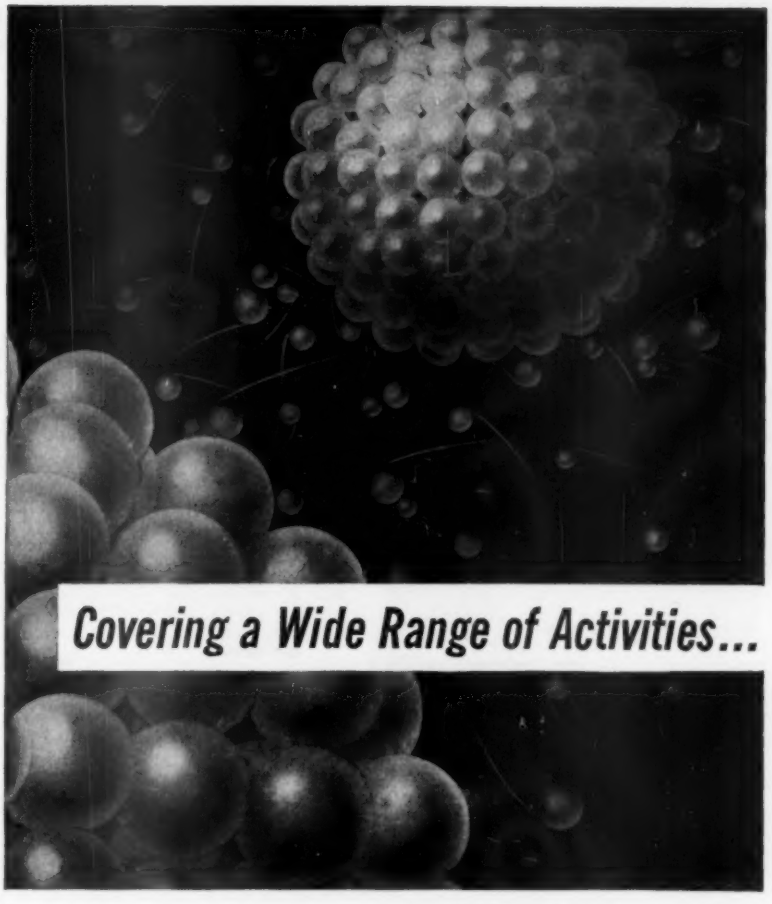
FIG. 1. HIGH-DOSE RESPONSE of 0.39-molar ceric-sulfate solution (A) shows gradual decrease of $G(Ce^{3+})$ at doses near 10^8 rads. Adding cerous ion (solution B) reduces initial G-value

titration with 0.01 *M* ferrous-sulfate solution (Baker and Adamson Special Reagent) in 0.8 *N* H_2SO_4 using 0.001 *M* ferroin indicator (G. F. Smith 1,10-*o*-phenanthroline ferrous sulfate). The colorimetric end point is sharp and reproducible. But since the indicator contains ferrous ion, a correction must be made in the titration calculations. Aliquots are diluted with 0.8 *N* H_2SO_4 before titration. The ferrous-sulfate concentration is determined by titration with ceric ammonium sulfate that has been standardized against pure iron wire. Due to the high ceric-ion concentrations involved, the spectrophotometric method is not used. Cerous-ion concentrations are approximate values calculated from weights of the added cerous sulfate.

Experimental Results

Figure 1 shows the large-dose relation between change in ceric-ion molarity and absorbed dose for two solutions, with and without initial cerous ions. With no added cerous ions (solution *A*), the curve is nonlinear throughout with an initial slope corresponding to $G(Ce^{3+}) = 3.1$ and a final slope corresponding to $G = 1.7$. The central portion of the curve has a slope of about $G = 2.5$ which agrees with *G*-values in the range 2.3–2.5 found by others for dilute ceric-sulfate solutions (*1*, *4–7*). Data for more dilute ceric solutions indicate an initial high slope and low terminal slope in all cases; the effect becomes more pronounced as ceric-ion concentration increases. The slope of the experimental curve changes only slowly as complete exhaustion of ceric ion is reached, and the yellow ceric solutions change abruptly to colorless cerous solutions as irradiation continues past the point of ceric-ion exhaustion.

Figure 1 also shows the effect of



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This article starts on page 102

adding cerous ion to solution *A* to see if a more useful dosimeter solution results. In this case (solution *B*), the initial slope is reduced to about 2.6 and the curve is nearly linear up to an absorbed dose of at least 0.5×10^8 rads. The final slope is comparable to that of solution *A*. There is a scatter of the points near complete ceric-ion exhaustion because of slight

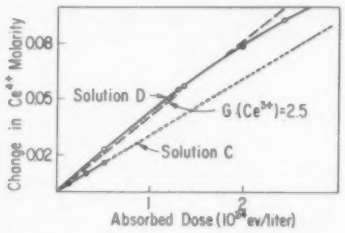


FIG. 2. DILUTE SOLUTIONS (C and *D*) respond with initial slopes that depend mainly on cerous-to-ceric ratio and have final slopes that are approximately equal

variations in the initial concentrations in some of the irradiated solutions.

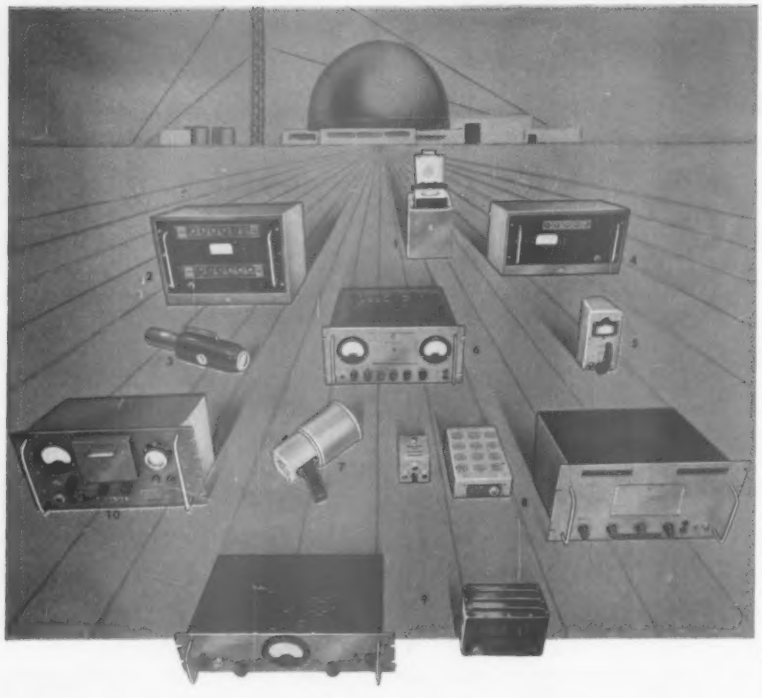
Figure 2 shows similar curves for more dilute cerium solutions *C* and *D* having initial cerous-to-ceric molar ratios of zero and eight. The two terminal slopes are nearly equal, as would be expected from the large initial cerous concentrations. The initial slope is a function primarily of cerous-to-ceric ratio with total cerium concentration causing a secondary effect at these large cerium concentrations.

The dose absorbed in the ceric solutions (D_v, ev/liter) is calculated from ferrous-ferric dosimeter measurements by the following equation, which corrects for differences in density and composition (*11*)

$$D_{v(\text{ceric})} = D_{v(\text{ferrous})} \times \frac{{}_m\mu_{en} d\ (\text{ceric})}{{}_m\mu_{en} d\ (\text{ferrous})}$$

${}_m\mu_{en}$ is the mass absorption coefficient (*12*) and d is the solution density. Values of the correction factor are shown in Table 1.

The solubility of $Ce(HSO_4)_4$ in 0.8 *N* H_2SO_4 at 23° C is 0.65 *M* in ceric ion. The practical concentration limit is somewhat lower than this, owing to difficulties with solids deposition in nearly saturated solutions. Attempts to reduce the hydrogen and sulfate-ion concentrations by dissolving $Ce(OH)_4$ or CeO_2 in sulfuric acid have not been successful because of their limited



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solubility and because of impurity contamination.

Discussion

There is no question about the nonlinearity of the 0.39 M ceric-sulfate dosimeter curve of Fig. 1. The data show that within the accuracy of the data, $G(Ce^{3+})$ decreases linearly with continued irradiation from an initial value of 3.1 to a final value of 1.7 (see Fig. 3). However, this behavior does not affect the usefulness of this dosimeter; in fact this property extends its range. For our 0.39 M ceric solution, the empirical relationship between $G(Ce^{3+})$ and ceric and cerous concentration (moles/liter) is

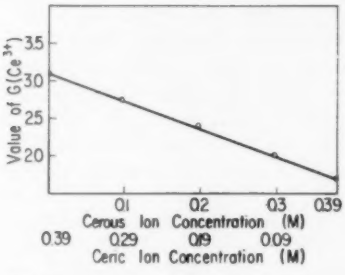

FIG. 3. VALUE OF $G(Ce^{3+})$ decreases linearly as 0.39 M ceric concentration is reduced by exposure to gamma photons

$$G(Ce^{3+}) = 3.1 - 1.4\,\frac{Ce^{3+}}{Ce^{3+} + Ce^{4+}}$$

Since $Ce^{3+} + Ce^{4+} = 0.39$ mole/liter, $G(Ce^{3+}) = 3.1 - 3.59Ce^{3+} = 3.1\ [1 - 1.16Ce^{3+}]$. Converting to differential form and integrating one has

$$\frac{dCe^{3+}}{dD_{v(ceric)}} = 5.15 \times 10^{-26}[1 - 1.16Ce^{3+}]$$

The resulting empirical dose-response equations for 0.39 M ceric solution are

$$D_{v(ceric)}\ (\text{ev/liter}) = -1.67 \times 10^{25} \log\,[1 - 1.16Ce^{3+}]$$

$$D_{g(ceric)}\ (\text{rads}) = -2.32 \times 10^{8} \log\,[1 - 1.16Ce^{3+}]$$

Table 2 compares the dose calculated from the first of these equations with that taken from the experimental curve in Fig. 1. Agreement is within 2%. It should be emphasized that this equation holds only for the 0.39 M ceric-sulfate solution. However, the constants depend only on the initial and final $G(Ce^{3+})$ during irradiation under conditions where the $G(Ce^{3+})$-vs-concentration curve is linear. Consequently, similar equations can be obtained for different ceric concentrations or other conditions used for further experimental study.

TABLE 2—Dose Comparison for 0.39 M Ceric Sulfate

Cerous concentration (M)	*Absorbed dose (10^{24} ev/liter)*	
	Experimental curve	*Empirical equation**
0.0	0.00	0.00
0.1	2.05	2.06
0.2	4.37	4.41
0.3	7.17	7.15
0.39	10.15	10.07

* $D_{v(ceric)} = -1.67 \times 10^{25} \ln [1 - 1.16 Ce^{3+}]$ or $D_{g(ceric)} = -2.32 \times 10^{8} \ln [1 - 1.16Ce^{3+}]$

Reaction Mechanism

The behavior of these concentrated ceric-sulfate solutions is in qualitative accord with the free-radical dissociation-and-recombination theory of water radiolysis and radical-diffusion models that have been proposed.

At low ceric-ion concentrations (10^{-4}–10^{-3} M), $G(Ce^{3+})$ equals 2.50. In 0.39 M ceric-sulfate solutions $G(Ce^{3+})$ increases to 3.1 because the $H + Ce^{4+}$ reaction now scavenges hydrogen atoms that normally combine to form hydrogen in dilute solutions. When the cerous concentration becomes high near complete depletion of ceric ion, an opposite action occurs. Hydrogen peroxide, formed by hydroxyl radical recombination, now decreases in yield because of the $OH + Ce^{3+}$ reaction. This reaction not only decreases the yield of the reducing species, hydrogen peroxide, but it also increases the yield of the oxidizing species. Consequently, drastic lowering in $G(Ce^{3+})$ from 2.5 to 1.7 results. As the solution becomes depleted in ceric ion, the $H + Ce^{4+}$ reaction becomes less important.

Further Study

These systems are interesting both in relation to high-level dosimetry and to the quantitative development of theories to explain the radiolysis of aqueous systems. Further dosimetry studies should include simplified means of predicting absorbed dose for solutions of any concentration, determination of the effects of dose rate at very high levels, and simplified means for controlling impurity effects without using components such as triply distilled water. Basic studies of reaction mechanisms should also include measurement of molecular-hydrogen, hydrogen-peroxide and cerous-ion yields as functions of cerous- and ceric-ion concentrations.

* * *

This article is based on a paper presented at the International Congress of Radiation Research, Burlington, Vt., Aug. 10–15, 1958.

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Vol. 17, Processing Irradiated Fuels and Radioactive Materials (709 pages, $18), is devoted for the most part to processing cycles; the last third of the volume is concerned with processing plant and equipment design and operation. About two-thirds of the processing papers are on the relatively traditional solvent-extraction techniques; experience gained at Windscale, with the fuel of the first Russian power station and at the JENER pilot plant, the ORNL Thorex pilot plant, etc., is described. The remainder of the processing papers are on pyrometallurgical techniques, almost all contributed by the U. S.

Vol. 28, Basic Chemistry in Nuclear Energy (686 pages, $18.50), presents material basic to fuel processing, analysis and homogeneous fuel systems. The first section covers mainly separation techniques, a number of the papers being on ion exchange. The papers of the second section discuss the chemistry of the actinides with particular attention to solvent-extraction properties. The last section reviews analytic programs of nuclear facilities and includes detailed papers on specific techniques.

Vol. 29, Chemical Effects of Radiation (475 pages, $14.50), presents basic studies of radiation effects. The first part is "Irradiation of Water and Aqueous Solutions," including several papers on the mechanisms of radiolysis of water. Following are "Irradiation of Organic Substances and Solutions" and "Irradiation of Polymers." The next sections contain papers related to organic moderators and coolants and solid materials for nuclear reactors as well as a number on the effects of radiation on free-radical reactions. The last parts of the volume discuss the use of fission products as radiation sources and other types of irradiation facilities

The Physics of Intermediate Spectrum Reactors

J. R. STEHN, editor (Naval Reactors Branch, Div. of Reactor Development, U. S. Atomic Energy Commission, Washington, D. C., 1958).

Reviewed by W. J. McCarthy, Jr., Nuclear and Analytical Div., Atomic Power Development Associates, Inc., Detroit, Mich.

The Naval Reactors Branch of the AEC has under preparation a three-volume Naval Reactors Physics Handbook. The present work is the third volume of the handbook, although it is the earliest to appear in print.

Since basic reactor physics techniques will be presented in the first volume, "The Physics of Intermediate Spectrum Reactors" is quite specialized. It is essentially an edited account of the theoretical and experimental reactor physics work that was done by Knolls Atomic Power Laboratory in connection, first, with the Intermediate Power Breeder project and, later, with the Submarine Intermediate Reactor (S1G) project that eventually led to the reactor for the Seawolf (S2G).

Much of the work has been reported before in the classified literature, but never in both a critically edited and coherently arranged fashion such as is here the case. Throughout the book careful attention has been given not only to presenting the method of attack on a problem and the solution but to the often more useful and historically more interesting aspect of the problem, which is the discussion of the circumstances that made a solution necessary and of the reasons that made unsuitable a solution using a standard technique.

The book is comprised of four distinct and rather independent parts. The first part considers the critical experiment program that was an outstanding feature of the KAPL effort and details a number of techniques that will be useful to experimenters in all fields of reactor physics.

The second part covers the work done in estimating and improving the reactivity lifetime of the design and considers both the estimation of fission-product poisoning in the spectrum of interest and the theoretical and experimental work done to determine the value of burnable poisons as an endurance-increasing measure. This part includes a useful and interesting description of the nuclear aspects of the early operation of the S1G. One hopes for a forthcoming parallel description of the later operation of S1G as well as that of S2G.

The third part discusses the broad problem of heat generation and distribution with emphasis on the application of multi-energy-group theory to this problem. The fourth and last part is concerned with reactor kinetics, with the emphasis on experimental techniques, in particular the reactivity oscillator technique. Classification appears to have reared its head in this area, however, and the discussion of reactor stability leaves one unsatisfied owing to the absence of a thorough design description of S1G including actual values of temperature and temperature differences.

Although the copy reviewed did not have a topical index, it is understood that subsequent printings will include this valuable feature. The book will be a useful source to many reactor physicists and to many more will offer a fascinating account of the solution of unique reactor physics problems by original and powerful techniques.

Fundamental Aspects of Reactor Shielding

By HERBERT GOLDSTEIN (Addison-Wesley, Reading, Mass., 1959, $9.50, xvi + 416 pages).

Reviewed by Everitt P. Blizard, Neutron Physics Div., Oak Ridge National Laboratory, Oak Ridge, Tenn.

Goldstein revealed himself as a lucid writer with his authoritative and useful "Classical Mechanics," which has gained wide acceptance as a graduate text. He now has chronicled the work of modern workers in the field of reactor shielding with equal lucidity.

For the physicist or mathematician who engages in shielding research, whether theoretical or experimental, Goldstein has collected and described the essential basic knowledge. It covers with admirable completeness the sources of radiation, interactions with matter and attenuation in thick shields.

In treating attenuation studies, which really constitute the meat of the book, Goldstein covers not just the central lines of research, but many lines that have contributed to the current state of the art. By so doing he will have stimulated more research and further development in avenues that have been explored but are far from exhausted. The methods he describes will also find application in related fields in which large attenuations are studied.

All known pertinent methods of attenuation calculation are described, completely and well, and basic data is presented in convenient tabular form. Experiments and experimental methods (including radiation detection) are covered. Thus the book serves as a penetrating guide to shielding lore, telling a shield designer of the proved methods of solving the basic problems. The book is not a handbook, however, and thus does not attempt to enable the reader to solve every problem with which he may be faced. For example, most shields are penetrated by one or more holes, such as coolant ducts, and these present some of the most difficult problems for a shield designer. Goldstein does not discuss this problem. Nor does he cover the geometric problems associated with calculation of doses or intensities from distributed sources, although some work of this type was used in the comparison of experiments with theory. The reader, however, is referred to other works that cover the current state of the art for these subjects. In fact, the references listed at the end of each chapter make up a complete bibliography of shielding methods.

"Fundamental Aspects of Reactor Shielding" stands alone as the authoritative treatise on the basic problems of attenuation through thick shields. The author himself has contributed much of the original work and is thoroughly conversant with all of it. It is remarkable that in spite of the complexity of the subject—a more difficult one than, for example, reactor physics—the book is easily read, appearing more as a story about the pursuit of elusive neutrons and photons than as an abstruse text on a complicated problem. Basic physics needed for shield calculations is presented clearly and in all the detail that general knowledge and the author's intuition permit. This book will be an essential part of every complete library on reactor physics.

Continued on next page

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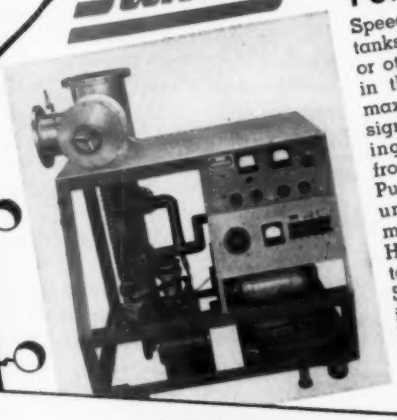

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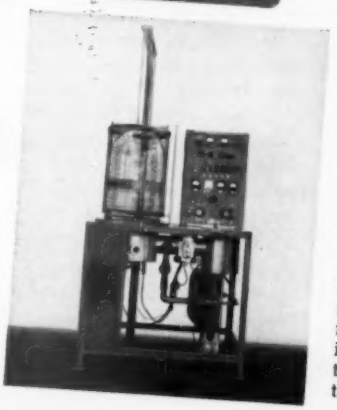

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BOOKS

Department starts on page 112

Materials for Nuclear Reactors

BERNARD KOPELMAN, editor (McGraw-Hill Book Co., New York, 1959, $12, x + 411 pages).

Reviewed by STANLEY KASS, Bettis Atomic Power Div., Westinghouse Electric Corp., Pittsburgh, Pa.

The editor of this book points out a continual need to tie together the informal publications issued under the auspices of the U. S. Atomic Energy Commission. The volume is "thus a handy first reference containing critical and selective reviews" presenting a "bird's-eye compendium of the advantages and of the limitations of materials as fuel elements, moderators, coolants, shields, and structure formers."

The various chapter authors have extracted the important information from approximately 400 references and have organized it in an admirable fashion. The result is a smooth story with none of the usual drawbacks of a literature survey. Each of the 10 chapters is well documented and is accompanied by a comprehensive bibliography.

The material is arranged logically, beginning with an excellent discussion of the extractive metallurgy of uranium, thorium, zirconium and beryllium, followed by a presentation of the characteristics of the metals, their alloys and ceramic fuels. From this point, the reader is taken through some of the methods of fuel-element fabrication and testing.

Radiation effects are discussed in Chapter 5, where the authors state: "To present in a limited space of a book chapter all the existing knowledge concerning reactor radiations and their many effects is an impossible proposition." To overcome the space handicap, a chart has been prepared providing a systematic general picture of the types of radiations encountered and their effects.

The remaining 100 pages of the volume discuss fluid materials of interest to the reactor engineer, corrosion problems, fuel reprocessing, moderator, shielding and control materials.

The volume contains a valuable collection of references to original work—an indication of the labor involved in preparation. The book is well produced; the text is clear and there are ample illustrations that greatly aid in following the text.

There is one basic difficulty involved in a book concerned with as wide a scope as a summary of materials, properties, fabrication and radiation effects: atomic research is advancing so rapidly that newer materials and processes are omitted and some of the conclusions are being challenged by recent information. However, this problem should not detract from the value of the volume in presenting the beginner and those unfamiliar with this highly specialized field a panoramic view of nuclear materials. For those actively engaged in the search for new materials, properties and processes or those requiring additional information, recent books dealing with specific materials will prove more useful.

1959 Atomic Industry Directory of Products, Equipment and Services. This directory is based on a survey of members of the Atomic Industrial Forum. The products, equipment and services of more than 200 organizations in the nuclear field are listed under more than 40 major categories and 130 subcategories. $2.50. *Atomic Industrial Forum, Dept. R, 3 E. 54th St., New York 22, N. Y.*

BOOKS RECEIVED

Worterbuch der Kernenergie, Englisch-Deutsch, by L. Franzen, L. Hardt and G. Muszynski (VDI-Verlag GmbH, Dusseldorf, Germany, 1957, DM 23.90, 240 pages). German equivalents of English nuclear terms are given plus a list of abbreviations and symbols.

Symposia of the American Society for Testing Materials. Radioisotopes—1956 (94 pages, $2.75); tracer applications, autoradiography, activation analysis, gaging. **Radiation Effects on Materials, Vol. 2—1957** (137 pages, $3.75); irradiation techniques, radiation effects on reactor materials. **Radiation Effects on Materials, Vol. 3—1958** (164 pages, $4.25); dosimetry, irradiation facilities, pressure-vessel design, effects on reactor materials and optical glass.

Nuclear Energy and the U. S. Fuel Economy, 1955–1980, by Perry D. Teitelbaum (National Planning Association, Washington, D. C., $3.00, xii + 188 pages, 1958). Sections of the book cover prospective energy prices, energy demand, nuclear energy costs and implications for the future. Most of the implications, however, concern the effect of nuclear energy on conventional fuel prices.

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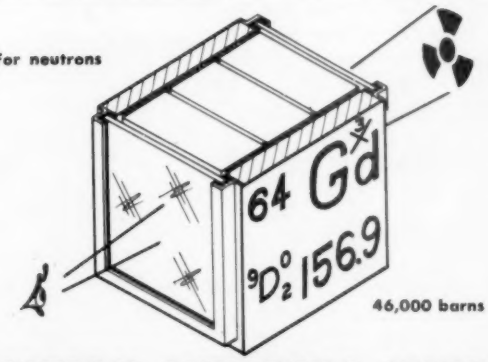

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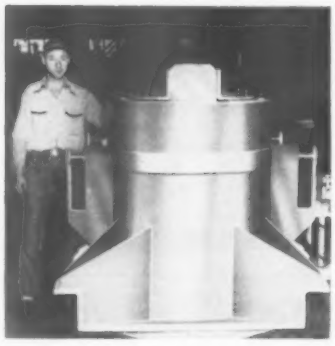

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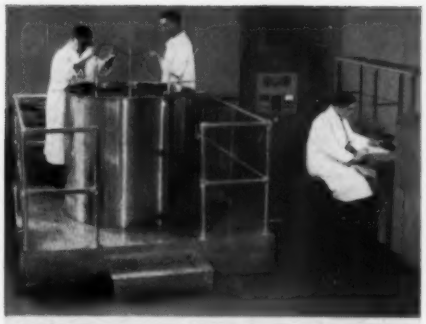

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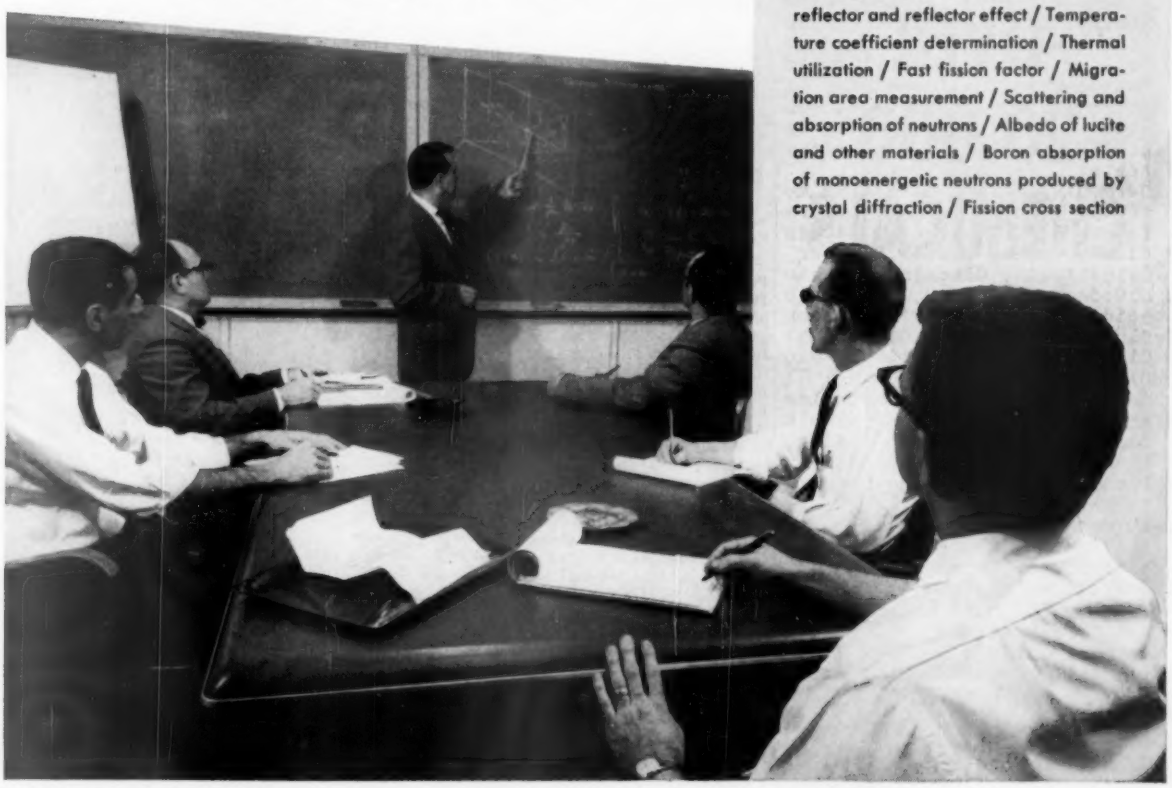

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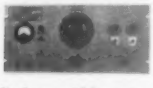

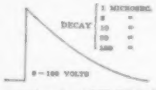

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Department starts on page 116

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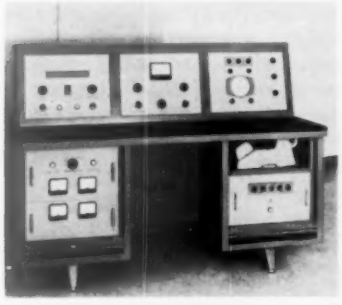
Personal Monitoring Film, Type 1	0.013	0.29	0.61	1.0	1.5	2.4	5.0
Personal Monitoring Film, Type 2 — Both emulsions	0.027	0.65	1.6	3.0	5.9	14	5.0
Personal Monitoring Film, Type 2 — Slow emulsion	2.6	51	140	320	1,300	2,800	4.2
Industrial X-ray Film, Type M	0.65	13	25	40	55	70	5.0
Industrial X-ray Film, Type AA	0.08	1.9	4.0	6.5	9.0	12	5.0
Industrial X-ray Film, Type F	0.024	0.71	2.0	5.0	—	29	3.8
Industrial X-ray Film, Type KK	0.013	0.29	0.61	1.0	1.5	2.4	5.0
Blue Brand Medical X-ray Film	0.045	1.1	3.5	—	—	22	2.9
Royal Blue Medical X-ray Film	0.024	0.71	2.0	5.0	—	29	3.8
Periapical Regular Dental X-ray Film, DF-19‡ (Single film packet)	0.40	10	30	70	300	1,000	4.2
Periapical Radia-Tized Dental X-ray Film, DF-7‡ (Single film packet)	0.11	2.5	6.0	10	15	22	5.0
Periapical Ultra-Speed Dental X-ray Film, DF-58‡ (Single film packet)	0.030	0.65	1.4	2.5	4.0	5.0	5.0
Occlusal Super-Speed Dental X-ray Film, DF-45‡ — Front Film	0.030	0.85	2.5	—	—	25	2.9
Occlusal Super-Speed Dental X-ray Film, DF-45‡ — Back Film	0.025	0.70	2.0	—	—	17	2.9
Fine Grain Positive Film	6.0	80	170	300	600	1,500	5.0

* These data are based upon 5 minutes development in either Kodak Rapid X-ray Developer or Kodak Liquid X-ray Developer and Replenisher at 68° F. Kodak No-Screen Medical X-ray Film is not suitable for radiation monitoring.

† The high-reference exposure is defined (American Standard PH2.10) as the smaller of the two exposures which will (a) produce a net density of 5.0 or (b) define a point on the shoulder of the characteristic curve at which the gradient is 0.1 times the maximum gradient.

‡ Lead-foil backed.

are 3 ohms to 5 megohms, capacitance limits are 500 $\mu\mu$f to 1,000 μf and inductance limits are 3 mh to 10,000 henries. Instrument has five meter ranges, indicating full-scale differences of 1%, 2.5%, 5%, 10% and 25%. Accuracy on range 1 is $\pm$0.1%. Especially designed bifilar bridge-type transformer provides stability.—Metronix, Inc., Chesterland, Ohio.



Pulse-Height Analyzer

Laben Type C31 (above) is 200-channel pulse-height analyzer designed for analysis of sequences of electric pulses by dividing same into 200 classes according to their linear or logarithmic amplitude. Spectrum of pulses examined is presented as 200 decimal numbers printed on tape; each number indicates number of pulses collected in each of 200 channels in which range between maximum and minimum amplitude of pulses is subdivided. Spectrum can be examined both during count and at end of same on screen of oscilloscope housed in unit. Difference between two spectra measured one after the other can be recorded. Analyzer uses 3,200-core magnetic memory.—Laboratori Elettronici e Nucleari, SRL, Milan, Italy.

Recording Oscilloscope

Model 1239A Fast Pulse Recording Oscilloscope is manufactured by Redcliffe Laboratories, Ltd., Bristol, England. The instrument is designed for viewing and photographic recording of fast-rising, low-duty-cycle transients of the order of 4-mμsec rise time, either nonrecurring or repetitive. It is particularly suited for single sweep application involving transients up to 10-μsec duration. Camera control circuits are designed so that exposure and film travel are fully automatic, permitting unattended operation over very extended periods. The basic deflection factor is 0.07 and 0.2 volt/cm with bandwidths of 79 and 140 Mc. Low

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PRODUCTS & MATERIALS

Department starts on page 116

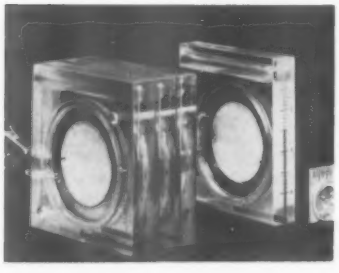
frequency response is 3 db down at 1 kc.—Kinbar Inc., 550 Fifth Ave., New York, N. Y.

Radiation Monitor

Type 6110 monitor measures gamma and beta radiation in 6 different ranges by decades from 1 mr/hr to 100 r/hr. Registration of total dose is made on a roller counter in steps of 1 r and when a dose of 10 r is received, the alarm is again triggered. The instrument is flashlight battery operated.—George T. Meillon Inc., 132 Nassau St., New York 38, N. Y.

Borated Graphite

Existing graphite grades are available with various percentages of boron carbides to produce effective thermal neutron shielding material. Size and boron content can be varied to meet different requirements.—Speer Carbon Co., Carbon Products Div., Saint Mary's, Penna.



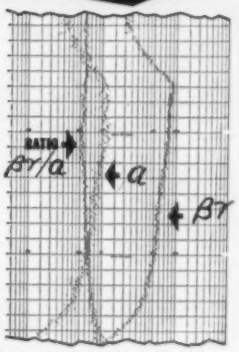
Ceramic-Disk Voltmeter

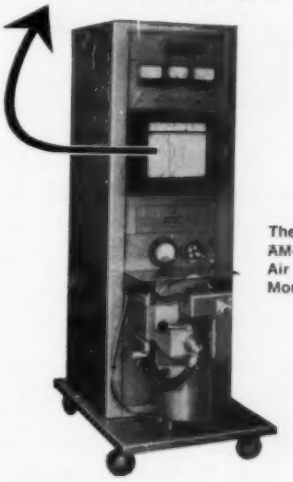
Prototype models (above) of new type voltage meter have electrostrictive ceramic discs as dynamic moving element. Each meter consists of small transparent block enclosing two opposing metal disks on which smaller discs of white ceramic have been bonded. Each ceramic wafer is coated on both sides with silver frit to form capacitor. When an electric potential is applied, ceramic contracts and cups metal disk. Colored fluid contained in reservoir between two plates is forced to rise in capillary tube at front of meter to provide visual indication of voltage. Surge chamber at top of block prevents buildup of back pressure.—Mullenbach Division, Electric Machinery Manufacturing Co., 2100 E. 27th St., Vernon, Calif.

LITERATURE AVAILABLE

Subject	*Length*	*Ask for*	*From*
Gas chromatography	4 pp.	"Aerograph Research Notes"	Wilkens Inst. & Research, Inc., P. O. Box 313, Walnut Creek, Calif.
U-Al fuel elements	4 pp.	Bulletin NU-3	M & C Nuclear, Inc., P. O. Box 898, Attleboro, Mass.
Research reactor and facilities	10 pp.	"Atomic Energy"	Armour Research Foundation, 10 W. 35th St., Chicago 16, Ill.
Rare-earth oxides	—	data sheet	Research Chemicals 170 W. Providencia St., Burbank, Calif.
Aluminum extrusions	16 pp.	"Heavy Press Extrusions"	Harvey Aluminum, 19200 S. Western Ave.,
Titanium	36 pp.	"Titanium"	Torrance, Calif.
Coordinate comparator	2 pp.	Bulletin 169-58	Gaertner Scientific Corp., 1201 Wrightwood Ave., Chicago 14, Ill.
Scintillation detector	2 pp.	Bulletin SC-2	Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.
Magnetic flowmeter	6 pp.	Catalog 10D1416	Fischer & Porter Co., 38 Jacksonville Rd., Hatboro, Pa
Spectrophotometry	8 pp.	"Spectrophotometry and the Chemist"	Matheson Coleman & Bell, 2909 Highland Ave., Norwood 12, Ohio
C^{14}-*l*-glutamine	—	Bulletin 144	Schwarz Laboratories, Inc., 230 Washington St., Mount Vernon, N. Y.
Impulse counting devices	4 pp.	"SODECO"	Landis & Gyr, Inc. 45 W. 45th St., New York 36, N. Y.
Magnesium oxide	12 pp.	"Advanced Materials Technology"	The Carborundum Co., P. O. Box 337, Niagara Falls, N. Y.
Heat-exchanger tubing	24 pp.	"Solving Corrosion Problems"	Bridgeport Brass Co., 30 Grand St., Bridgeport 2, Conn.
Laboratory furniture	4 pp.	"Unitized"	Fisher Scientific, 645 Fisher Bldg., Pittsburgh 19, Pa.
Well logger	9 pp.	"Radiation Well Logger"	McCullough Tool Co., Los Angeles, Calif.
Nuclear instruments	76 pp.	General Catalog R	Nuclear-Chicago Corp., 229 W. Erie St., Chicago 10, Ill.
Reactor-plant operation	14 pp.	"Something of Your Future"	Nuclear Science & Eng. Corp., P. O. Box 10901, Pittsburgh 36, Pa.
Engineering drawings	4 pp.	"New Material"	Cooper-Trent Corp., 2701 Wilson Blvd., Arlington 1, Va.
Radiation protection for physicians	—	Radiation-protection motion picture	The American College of Radiology, 20 N. Wacker Dr., Chicago 6, Ill.
Nuclear reactor simulator	8 pp.	Bulletin B130-1	Minneapolis-Honeywell, Wayne & Windram Aves.,
Recorders-indicators	40 pp.	Catalog C15-1	Philadelphia 44, Pa.
Advanced magnets	4 pp.	"Advanced Magnets for Power Control"	Milro Controls Co. Hawthorne Ave., Park Ridge, N. J.

This Air Monitor Solves the Natural Radon Progeny Problem





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INDUSTRY NOTES

• **NUMEC,** Apollo, Pa., expects to break ground early this month for a $300,000 plutonium-fuel development facility at Leechburg, Pa.; the expandable lab will have 18,000 sq ft of space.

• **Tracerlab** is investigating capabilities and facilities of several European instrument companies with an eye to licensing arrangements for European manufacture of Tracerlab products. Final arrangements with several firms were being formulated, according to S. S. Auchincloss, Tracerlab president. A. Gilles, president of **Saphymo**, French distributor of Tracerlab instruments, recently visited Tracerlab to discuss such a manufacturing arrangement.

• AEC has licensed **Coastwise Marine Disposal Co.** to handle and dispose of nuclear wastes in the Pacific Ocean.

• **Western Nuclear Co.** has shut down its uranium mill at Jeffrey City, Wyo., for an undecided period because of overproduction of concentrates. The company is proceeding with expansion of its mining operations, however, under long-range arrangements with AEC.

• The Rare Earth and Thorium div. of **Michigan Chemical Corp.** is moving its Minerals Exploration unit from Idaho Springs, Colo., to company headquarters at Saint Louis, Mich. Aim is a closer relationship between field and ore-concentration activities and analytical and chemical research at the rare-earth plants.

EXPANSIONS. A West Coast division at 1717 S. Victory Blvd., Glendale, Calif., has been set up by **Nuclear Consultants Corp.** of St. Louis; the division will function as a sales office, lab, headquarters for a group of consulting physicists, and distribution point for NCC's line of radiopharmaceuticals and tagged compounds. . . . **Technical Measurement Corp.** has moved into a new plant at North Haven, Conn.; the 11,000 sq ft building will house engineering, production and administration. . . . **Edgerton, Germeshausen & Grier** expects a new research-development facility at Santa Barbara, Calif., to be ready Nov. 1; up to 50 people—mostly scientists and engineers—are to be employed in the first year to work on advanced projects of a nuclear, missile or space nature. . . . **American Metal Products Co.** has recently established a program of nuclear and missiles material development within its Engineering Science div. Nuclear emphasis is on high-temperature materials for power reactors, Leslie H. Landrum has joined the firm from Spencer Chemical Co. to direct the program. . . . **Superior Tube Co.,** Norristown, Pa., has completed a $2-million expansion project at its headquarters plant, much of the new space will be used for processing of zirconium, hafnium and other tubing.

FINANCIAL. A 2-for-1 stock split has been approved by stockholders of **Baird-Atomic.** Also voted was an increase in the number of authorized common shares from 500,000 to 1,500,000; 180,000 shares will be offered for public sale to repay $1.1-million in short-term loans and to finance $1-million in new or acquired plant facilities. . . . **Radiation, Inc.,** Melbourne, Fla., reported $8-million in orders blacklog during June—40% ahead of June '58. . . . **Lithium Corp.** expects a drop in '60 sales and earnings because of an end in AEC lithium purchases as of Dec. 31 this year. However, LCA President Herbert W. Rogers predicted a resumption of AEC buying "within a reasonable time"; there appears to have been no shift by AEC away from lithium use, he said. He revealed that AEC has freed LCA of all obligations to repurchase depleted materials.

NEW BUSINESS. A contract has been awarded **Stromberg-Carlson div.** of General Dynamics to supply all instrumentation, safety systems and intercommunication equipment for the skid-mounted power reactor being delivered by Alco Products to the Army Corps of Engineers (March '59, 25). . . . **High Voltage Engineering** has sold a 10-Mev tandem Van de Graaff accelerator to the Universitet Institut for Teoretisk Fysik, Copenhagen, Denmark; it will be used for fundamental investigation of atomic nuclei. . . . **Technical Operations,** under a contract with the Materials Laboratory of the Wright Air Development Center, has launched a research program to simulate certain effects of nuclear weapons on materials; a new building will be erected at Burlington, Mass., headquarters to house apparatus for the Air Force study.

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Complete up-dating of the table on nuclear fleet (see July, 1957 NUCLEONICS) . . . what companies are building what parts . . . what it means for companies to work for nuclear navy builders . . . new companies in the field . . . interviews with top Navy officials on their philosophies and plans for the future . . . dollar figures, forecasts and trends.

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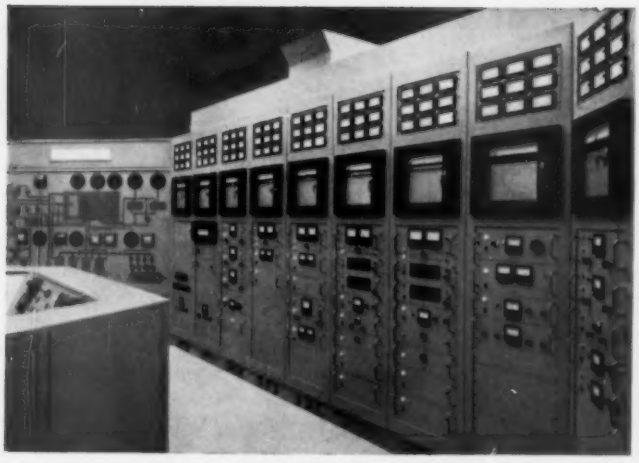
NUCLEAR CAMPUS

• **CAMPUS FACILITIES.** **Texas A&M** has asked bids from at least four reactor manufacturers for the two-core, swimming-pool reactor it plans to build as a major facility of its Nuclear Science Center. Bids have been solicited from AMF Atomics, General Electric, Curtiss-Wright, Babcock & Wilcox and others, as well as Convair div. of General Dynamics, which is architect-engineer for the reactor. . . . The **Univ. of Florida's** 10-kw training reactor has had its first fuel loading—24 plate-type elements enriched to 20% uranium-235—and was to go to full power after several test runs at low power. . . . **West Virginia Univ.** expects completion in June '60 of an AGN-211, pool-type reactor ordered from Aerojet-General Nucleonics; the reactor will be installed in the basement of the physics building in a reactor room 21 × 27 × 28 ft high. . . . **Cornell Aeronautical Laboratory** is making grants of $50,000 each to the reactor projects of **Cornell Univ.** and the **Univ. of Buffalo** (NU, May '59, 208); both reactors will be made available to CAL. "An interesting feedback relationship exists here," said CAL President Ira G. Ross. "As the nuclear capability of our own staff is increased by the availability of these reactors and related courses, it is reasonable to expect that the Laboratory will participate more heavily in original nuclear research. Such research will in turn generate additional use of the reactor facilities." . . . **Washington State College** expects its 1-Mw research reactor to go into operation this summer.

• **PERSONNEL NOTES.** **Frederick Reines,** a group leader at Los Alamos Scientific Laboratory, has been named Ambrose Swasey Professor and head of the Physics dept. at **Case Institute of Technology.** **John S. King,** manager of the critical assemblies laboratories at Knolls Atomic Power Laboratory, has been appointed associate professor nuclear engineering at the **Univ. of Michigan** for a 2-year period beginning this fall.

Courses

Medical aspects of radiological health is offered Nov. 30–Dec. 11 by the Robert A. Taft Sanitary Engineering Center, Cincinnati; it is designed for medical, dental and biological personnel from federal, state and local health agencies.



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Instrument panel for a 20 MW High Flux tank-type reactor. Graphic panel at the left includes flow and pressure meters for the cooling circuits. Centre section houses neutron flux measuring channels with recorders for flux and period as well as recorders indicating coolant temperatures. Righthand panels contain radioactivity monitors for water and gas circuits. Indication of abnormal operating conditions is provided by annunciators above recorders.

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NEWSMAKERS

Personnel developments at Argonne National Laboratory include: (1) **Kundan S. Singwi** of India's Atomic Energy Establishment has accepted a two-year appointment as a resident research associate; (2) eleven staffers have been promoted to senior scientist or engineer—**Raymond O. Brittan, James A. DeShong, Jr., Harry H. Hummel, Leonard E. Link** and **W. Charles Redman** (all reactor engineering), **Johan E. A. Graae, Milton Levenson** and **John H. Schraidt** (chemical engineering) and **Leroy R. Kelman, Robert E. Macherey** and **Arthur B. Shuck** (metallurgy); (3) **Cornelius S. Kipfer** has been named superintendent of ANL's central shops where special research equipment is engineered and built. Kipfer succeeds **Herbert V. Ross,** who recently joined Combustion Engineering.

Vice-presidencies at Vitro Engineering have gone to **Sydney M. Stoller,** engineering manager, and **Jack L. Schumann,** sales manager.

Richard W. Cook, formerly deputy general manager of AEC, has been appointed deputy group executive and divisional vice-president of American Machine & Foundry's Government Products group. He adds these two positions to those he had already held at AMF—group executive of the Atomic Energy group and a director of AMF Atomics of Canada.

Cook

John B. Darrah has been named vice-president and general manager of the Budd Company's Defense div., which Budd says "is taking an increasingly active role" in both the naval reactor program and the aircraft nuclear program. Darrah had been active in the company's ANP activities as assistant works manager in charge of dies, jigs and fixtures.

Darrah

Saul J. Harris has left his post as assistant manager of technical services, Atomic Industrial Forum, to join Atomic Accessories as technical director.

J. Donald Rauth, general manager of Martin Co.'s Nuclear div., has added a vice-presidency to his general manager's title; he had managed the division only a year. Martin said the promotion was based, among other things, on the Nuclear div.'s development of a small power reactor for Air Force use and SNAP-3, a thermoelectric device using a radioisotope for heat.

Rauth

A scientist who collaborated in the separation of uranium-235 from natural U just 20 years ago, **Kenneth H. Kingdon,** has retired after 39 years with the General Electric Research Laboratory. Kingdon also made important contributions to large-scale separation of U-235 during World War II and to the founding of Knolls Atomic Power Laboratory. He is succeeded at GE by **Leslie G. Cook** as manager of the Research Lab's Project Analysis section. In other manpower developments at GE, **William N. Oberly** has been named manager of production and marketing research, Atomic Power Equipment dept., and **Edward de Grazia** has joined the APED legal staff.

Kingdon

Personnel changes at Tracerlab: **William A. Stenzel** has shifted from public relations and advertising manager to nuclear sales manager; his successor is **Paul A. McNulty; Alexander M. Filipov** has joined the program for development of instruments for detection, analysis and measurement of radiation; and **Frederick J. Walsh, Jr.,** has been appointed manager of operations in the Contract dept.

J. E. Cunningham of Southwestern Public Service Co. and **H. R. Drew,** an engineer, have been elected president

and executive vice-president, respectively, of the Texas Atomic Energy Research Foundation.

D. F. Cope, deputy director of Oak Ridge National Laboratory's Research and Development div., has been promoted to director of the Reactor div., newly organized to coordinate the several reactor programs at ORNL.

William E. Parker has left the Nuclear Systems div. of Budd Co. to supervise the Carbon and Graphite Research group at Speer Carbon Co.

Three important posts have been filled in the Engelhard Industries organization. At the D. E. Makepeace div. **John C. Robinson,** formerly of AEC, General Electric, Sylvania-Corning and Martin, has been named senior metallurgist on the staff of the fuel-element fabrication group. At Nuclear Corp. of America, **Alfred A. Michaud** has been named vice-president and general manager of the West Coast div. And **Ronald C. Vickery** has been named senior research scientist of the Research Chemicals div.

Allen M. Goldstein has been elected president of U. S. Nuclear Corp., Burbank, Calif.

New Jersey has lost its chief radiation officer, **Byron K. Keene,** to Nuclear Engineering, California. Keene will be radiation protection officer in charge of NE's eastern area of operation with offices in Kearney, New Jersey. **Edgar A. O'Neil** has been named atomic energy adviser to New Jersey's Department of Conservation and Economic Development.

Eight key posts for the Hanford plutonium-reactor project have been assigned by Kaiser Engineers, prime construction contractor: **John H. Tacke,** resident manager for all construction activity; **Hugh Fulton,** assistant to Tacke; **George L. Roberts,** construction engineer; **Park N. Savage,** general construction superintendent; **G. M. Abraham,** subcontracts engineer; **Paul V. McBride,** administration manager; **A. L. Gordon,** industrial relations director; and **L. R. Manis,** procurement manager.

Malcolm F. Judkins has been appointed technical director, commercial production engineering, Sylvania-Corning Nuclear Corp. Judkins joined Sylcor from Firth Sterling, Inc., where he directed new-product development.

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Aug. 9–12—Third Joint Heat Transfer Conference, sponsored by American Society of Mechanical Engineers and American Institute of Chemical Engineers, Storrs, Conn. (*Univ. of Conn.*). Contact ASME, 29 W. 39th St., N. Y. 18, N. Y.

Aug. 17–21—4th International Conference on Ionization Phenomena in Gases, Uppsala, Sweden. Program includes high-temperature plasmas and controlled fusion. Abstracts due June 15 (350 words). Contact Ake Nilsson, Institute of Physics, Uppsala.

Aug. 20–21—Symposium on Industrial Uses of Radioisotopes, Buffalo, sponsored by Chamber of Commerce, Canisius College and Univ. of Buffalo in cooperation with AEC Office of Isotopes Development. Contact Charles F. Light, Buffalo C. of C., 238 Main St., Buffalo 2, N. Y.

Sept. 5–11—Conference on Application of Large Radiation Sources in Industry, with emphasis on chemical processing, Warsaw, Poland. Contact A. I. Galagan, IAEA, United Nations, N. Y., or IAEA, Vienna.

Sept. 14–19—International Conference on High Energy Accelerators and Instrumentation. Contact CERN Conference Secretariat, Geneva 23, Switz.

Sept. 21–25—Annual Conference and Exhibit, Instrument Society of America, Chicago (*downtown hotels, amphitheater*). Contact ISA, 313 Sixth Ave., Pittsburgh 22.

Sept. 22–24—3rd Industrial Nuclear Technology Conference on nonpower applications of nuclear technology, cosponsored by Armour Research Foundation and NUCLEONICS, Chicago (*Morrison*). Contact Leonard Reiffel, ARF, 10 W. 35th St., Chicago 16, Ill.

Sept. 28–Oct. 1—Ninth Annual Instrument Symposium and Research Equipment Exhibit, Bethesda, Md. (*National Institutes of Health*). Contact James B. Davis, NIH, Public Health Service, Bethesda 14.

Sept. 28–Oct. 1—National Power Conference, cosponsored by American Society of Mechanical Engineers and American Institute of Electrical Engineers, Kansas City (*Muehlebach*). Contact ASME or AIEE, 33 W. 39th St., N. Y., N. Y.

Oct. 6–9—International Symposium on High-Temperature Technology, Asilomar, Calif., sponsored by Stanford Research Institute. Contact Dept. 734, SRI, Menlo Park, Calif.

Oct. 7–9—National Symposium on Vacuum Technology, sponsored by American Vacuum Society, Philadelphia (*Sheraton*). Several nuclear sessions. Contact C. B. Willingham, AVS, Box 1282, Boston, Mass.

Oct. 14–16—12th Annual Gaseous Electronics Conference, sponsored by Electron Physics div. of American Physical Society and National Bureau of Standards, Washington, D. C. (*Sheraton-Park*). Contact L. M. Branscomb, NBS, Washington, D. C.

Oct. 15–16—Radiation Effects Symposium of Glass Div., American Ceramic Society, Galen Hall, Pa. Contact Norbert Kreidl, Bausch and Lomb Optical Co., Rochester 2, N. Y.

Oct. 26–28—Third Conference on Analytical Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn. Contact C. D. Susano, Oak Ridge National Laboratory, P. O. Box Y, Oak Ridge, Tenn. (papers), or Tom Woods, Mgr., Mountain View Hotel, Gatlinburg (accommodations).

Nov. 2–6—Joint Meeting of Atomic Industrial Forum and American Nuclear Society, Washington, D. C. (*Sheraton Park*). AIF's annual meeting scheduled first three days (Nov. 2–4), ANS' semiannual meeting begins third day (Nov. 4–6). For AIF meeting contact AIF, 260 Madison Ave., N. Y. 18, N. Y.; for ANS meeting contact ANS, John Crerar Library, 86 E. Randolph St., Chicago 1.

Nov. 4–6—National Automatic Control Conference, Dallas (*Sheraton*), sponsored by Institute of Radio Engineers. Also participating: American Institute of Electrical Engineers and Instrument Society of America. Contact G. S. Axelby, Westinghouse, Box 746, Baltimore 3, Md.

Nov. 4–6—Eastern Analytical Symposium and Instrument Exhibit, New York City (*New Yorker*), sponsored by four Eastern sections of Society for Applied Spectroscopy, among others.

Nov. 16–21—Conference on Disposal of Radioactive Wastes, Monaco, sponsored by International Atomic Energy Agency. Contact IAEA, 11-13 Karntnerring, Vienna 1.

Nov. 19–20—Sixth Annual Meeting of the Professional Group on Nuclear Science of the IRE in conjunction with the New England Regional Electronics Meeting, Boston, Mass. (*Commonwealth Armory*). Contact Hugh Stoddart, Atomium Corp., 940 Main St., Waltham, Mass.

Feb. 25–26—7th Scintillation Counter Symposium, Washington, D. C. (*Shoreham*). Deadline for abstracts is Dec. 15. Contact G. T. Reynolds, Princeton Univ., Princeton, N. J.

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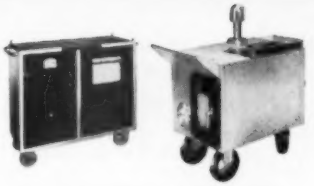

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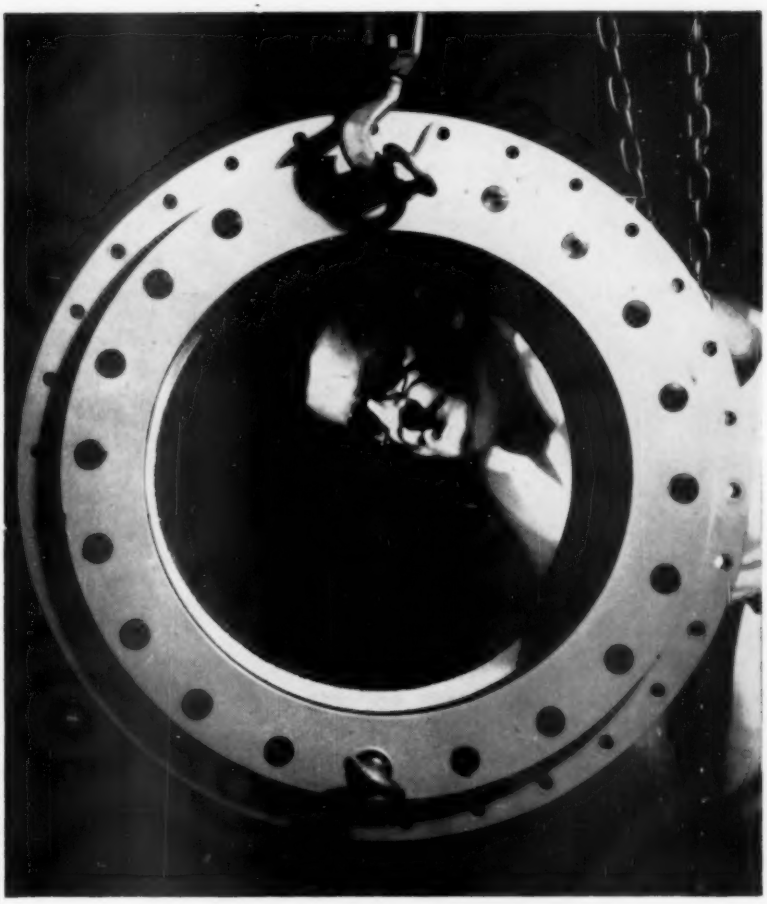
INDEX TO ADVERTISERS

AUGUST 1959

Allegheny Ludlum Steel Corporation 13
Ameray Corporation 48
American Laundry Machinery Company 98
American Tradair Corp., Ekco Electronics, Ltd. 110
Amphenol Cable & Wire Division Amphenol-Borg Electronics Corporation 49, 50
Anton Electronic Laboratories, Inc. 129
Atomics International, a Division of North American Aviation, Inc. . . 83, 106, 107
Autonetics, a Division of North American Aviation, Inc. 47
Babcock & Wilcox Company Atomic Energy Division . . 1
Boiler Division 32
Baird-Atomic, Inc. 85
Barnstead Still & Sterilizer Co. 6
Bendix Aviation Corporation Cincinnati Division 126
Blickman, Inc., S. 56
Carboline Company 94
Carlson Inc., G. O. 30
Central Research Laboratories, Inc. 35
Cleveland Hard Facing, Inc. 9
Columbia-Geneva Steel . . 38, 39
Consolidated Electrodynamics 105
Corning Glass Works 135
Crawford Fitting Company . 45
Curtiss-Wright Corporation . 117
Delta Chemical Works, Inc. . 118
Ebasco Services 31
Electric Steel Foundry Company 15
Electronic Associates, Incorporated 12
Ex-Cell-O Corporation . . 10, 11
Federated Metals Division of American Smelting and Refining Company 33
Fenn Manufacturing Company 101
Film Badge Service 130
Foxboro Company 40
Gaertner Scientific Corporation 103
General Atomic Div. of General Dynamics Corp. 115
Graham Manufacturing Co., Inc. Heliflow Corporation 96

Griscom-Russell Company, a Subsidiary of General Precision Equipment Corp... 44
Hamner Electronics Co., Inc. 2nd Cover
Illinois Water Treatment Co. 88
Interstate Industrial Uniform Rental Service, Inc.....122
Kaiser Engineers ....3rd Cover
Keithley Instruments, Inc. ... 36
Kinney Mfg. Division, The New York Air Brake Company 113
Leeds & Northrup Co..... 89
Levinthal Electronic Products, Inc. 127
Los Alamos Scientific Laboratory 120
M & C Nuclear, Inc. a Subsidiary of Texas Instruments Incorporated 2, 56, 87
Magnetrol, Inc.....134
Mallory-Sharon Metals Corporation 5
Marman Division, Aeroquip Corporation 127
National Carbon Company Division of Union Carbide Corp. .....4th Cover
New York Air Brake Co...113
Norton Company.....109
Nuclear-Chicago Corporation 52
Nuclear Development Corporation of America.... 16
Nuclear Enterprises Ltd....126
Nuclear Equipment Department Mechanical Division of General Mills..... 14
Nuclear Laundry Service Inc. 34
Nuclear Measurement Corp. 121
Nuclear Shielding Supplies & Service.....130
Nucleonics 34
Pechiney Division Applications Atomiques..... 37
Penberthy Instrument Co...115
Philips' Gloeilampenfabrieken N.V.....125
Picker X-Ray Corporation.. 43
Pittsburgh Piping & Equipment Company..... 46
Purolator Products, Inc.....115
Pye Limited..... 54
Radiation Counter Laboratories Inc..... 29
Radiation Dynamics, Inc... 53
Radiation Instrument Co...118
Radiation Instrument Development Laboratory, Inc..136



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Rocketdyne, A Division of North American Aviation, Inc. 90
St. John X-Ray Laboratory . 130
Searchlight Section . . . 130–133
Stromberg-Carlson Division of General Dynamics Corporation 57
Superior Steel Division of Copperweld Steel Company 41
Sylvania-Corning Nuclear Corp. 58
Technical Associates 102
Technical Measurement Corporation 8
Teleflex Incorporated 51
Tennessee Coal & Iron . . 38, 39
Texas Nuclear Corporation . 34
Union Carbide Metals Company, Division of Union Carbide Corp. 91
United States Steel Corporation 38, 39
United States Steel Export Company 38, 39
Victoreen Instrument Company 7, 119
Vitro Engineering Company, A Division of Vitro Corporation of America 99
Vitro International, A Division of Vitro Corporation of America 108
Wall Colmonoy Corporation 134
Westinghouse Atomic Power Dept. 128
Where To Buy 130
Zallea Brothers 55

•

PROFESSIONAL SERVICES . . 130
CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.

EMPLOYMENT OPPORTUNITIES 130–133
Allis-Chalmers Manufacturing Company 130
Armour Research Foundation of Illinois of Technology 133
Atomic Energy Commission 130
Atomic Personnel, Inc. 132
Babcock & Wilcox Co., The 131
Battelle Memorial Institute 132
Cook Electric 130
Esquire Personnel 130
Fidelity Personnel 131
General Electric Company 133
General Nuclear Engineering Corp. 133
Internuclear Company 132
Minneapolis-Honeywell Regulator Co. 132
Nuclear-Chicago Corporation . . . 131
Warner, C. S. 133

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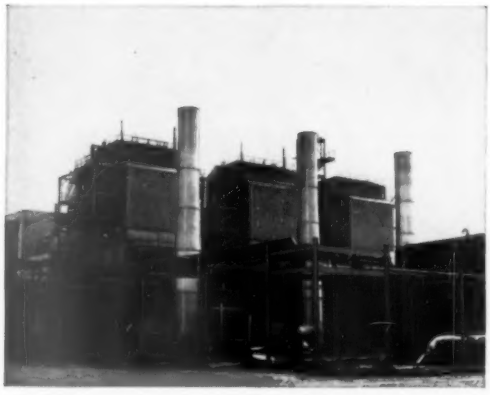

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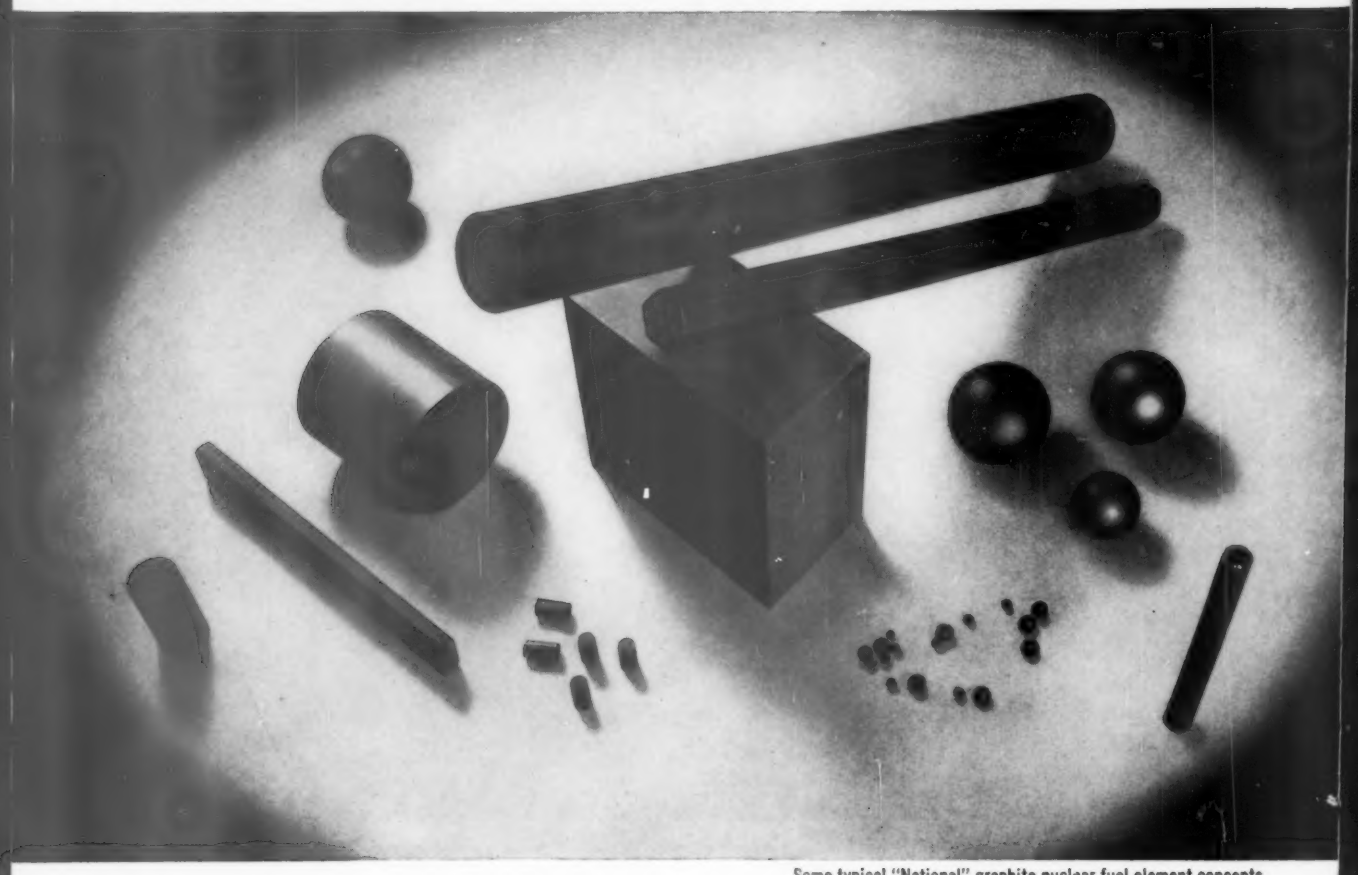

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